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Vol. XV, No. 2
May 1958

INDUSTRIAL QUALITY CONTROL

JOURNAL OF THE AMERICAN SOCIETY FOR QUALITY CONTROL

NLS 481 Simplifies and Accelerates Power Supply Testing

Many manufacturers are finding that power supply testing is greatly accelerated by the NLS 481 Digital Voltmeter. During regulation tests, changes of 0.01% in output voltages are measured and displayed *instantly* . . . in one-tenth of the time required by manually-operated instruments! As the voltage changes, the 1-inch numerals change on the easy-to-read illuminated readout.

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Which speaker is making the sound? In echoless chamber at Bell Labs, Robert Hanson measures test subject's ability to localize sounds — observes how two ears operate in partnership. This and other tests may point the way to better telephone instruments.

In listening to stereophonic music, how is it that our ears and brain construct a picture of the entire orchestra with but two samples (the sounds from two speakers) to work with?

How is it that our ears and brain are able to pinpoint *one* voice in a roomful of talkers—to listen to it alone and ignore the rest?

What makes *two* ears better than one?

Bell Telephone Laboratories scientists are searching for the answers. For in finding them, better telephone instruments and better ways of transmitting sound will surely result.

Our hearing performs feats that no electronic system can yet duplicate. How? Laboratories scientists believe the secret lies in the way our two ears function in partnership and in the way our neural network connects them with our brain. *The problem:* to discover what functions the network performs and to see whether electronic duplication might enhance understanding.

The work is under way. Electronic circuits that simulate the operation of nerve cells have already been created—and conceptual models of the neural network are being constructed.

Alexander Graham Bell's interest in deafness and hearing led to the invention of the telephone. Bell Laboratories' current explorations in binaural sound may well lead to important new advances in the transmission of speech and music.

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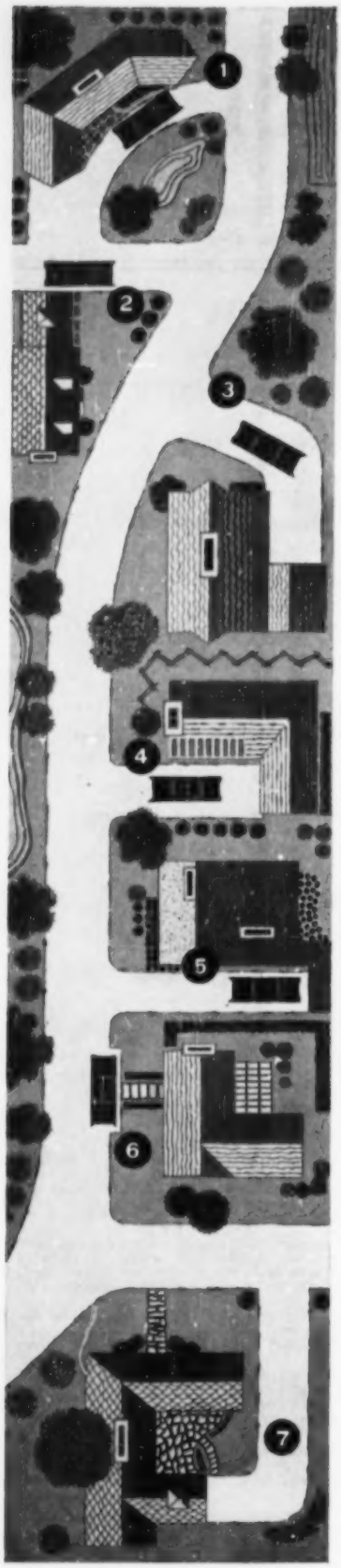
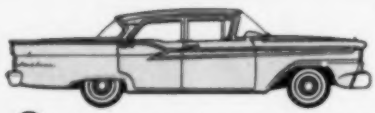
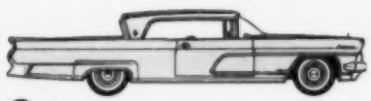


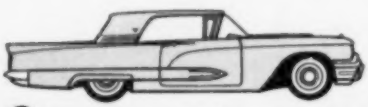
No Conformists on This Street!



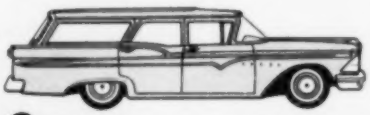
❶ It's the Ted Stephens family in their spanking new Ford Fairlane on their way home from Sunday services. *Here's the four-door sedan they drive.*



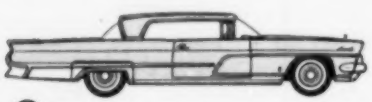
❷ Joe Mitchell's new Continental Mark IV gets the once-over by his partner, Cliff Potter, before their weekly golf date. *Picture this in your driveway!*



❸ After much pleading, Sue Grant finally wheedled dad's new T-Bird out of him—she's a big-time sorority girl now. *And this new beauty carries four.*

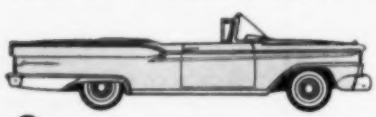


❹ That's Ethel and Jack Steele loading their Edsel station wagon for a picnic in the country with the kids. *Here's the nine-passenger, four-door model they chose.*



❺ There goes Doctor Summers' new Lincoln Premiere hurrying off to the city hospital. The Elliot baby is on the way! *This is the car his patients recognize.*

❻ The new Mercury Park Lane in the Wilson driveway really sparkles—young Jimmy gets a dollar each time he washes it. *Here it is. See what we mean?*



❼ Who's missing? The Smiths—June, Fred, Timmy and Tommy. They left early in this Ford convertible for a two-week vacation in the sun.

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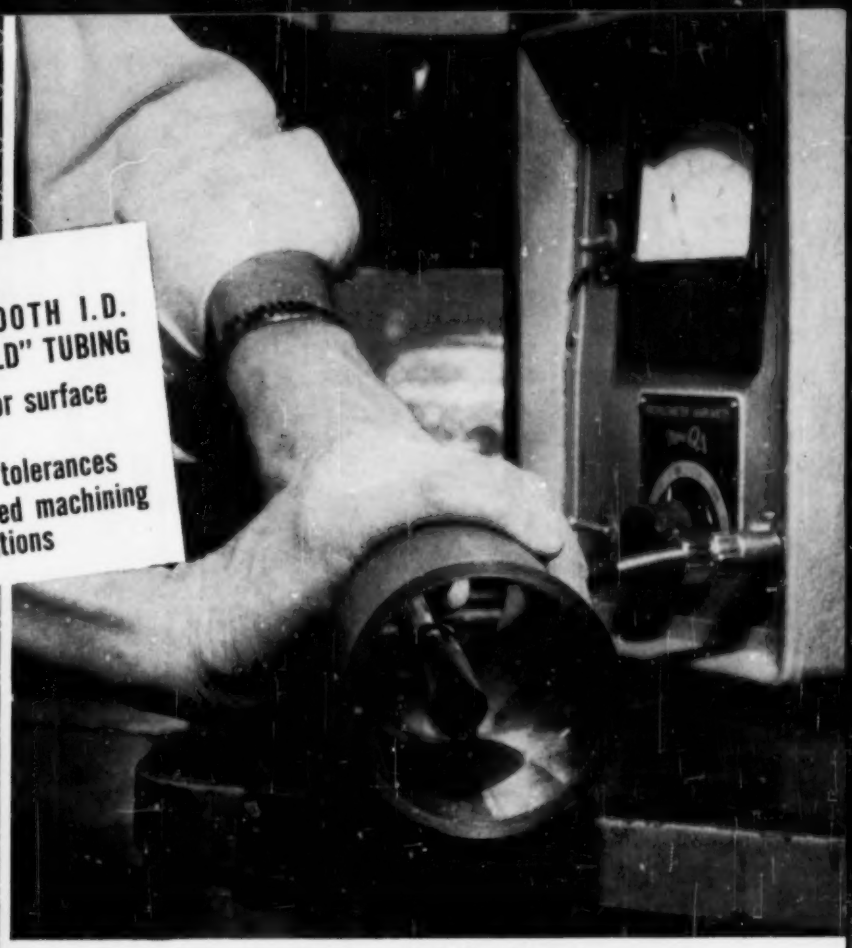

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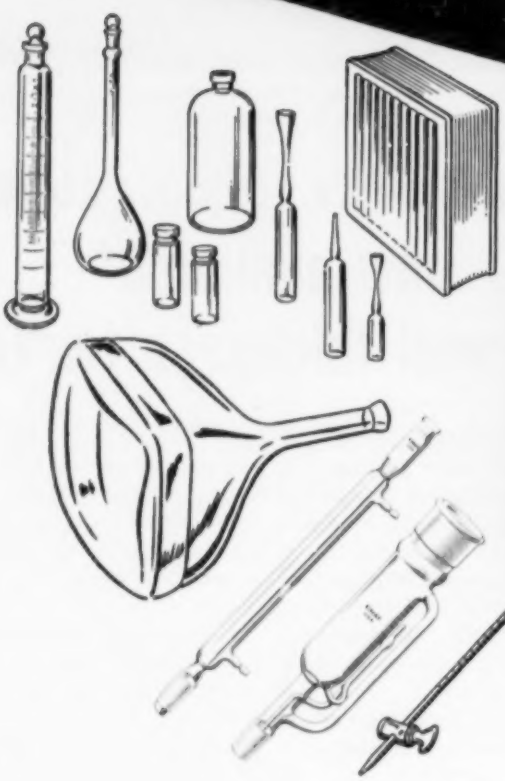

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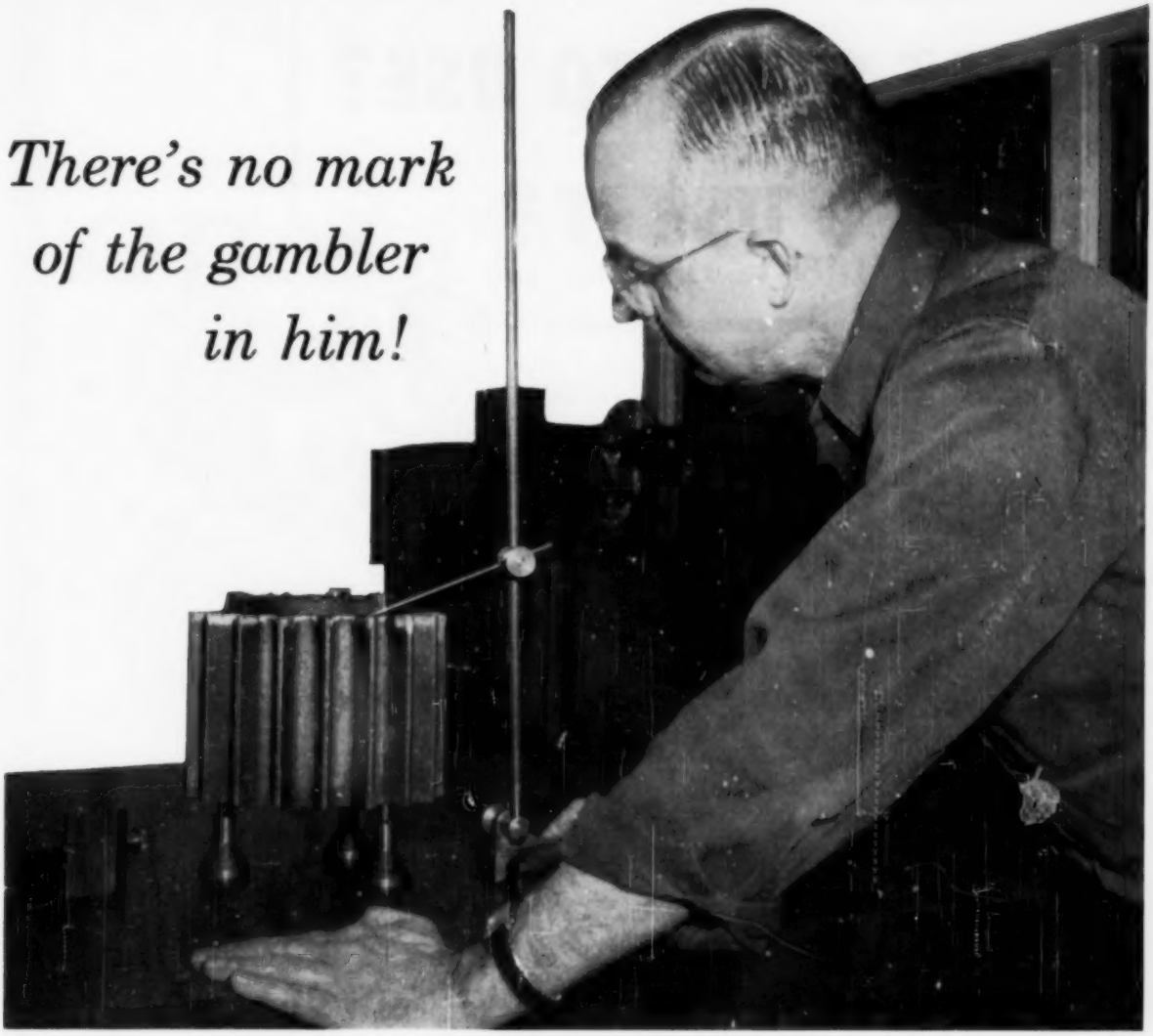
There's no mark of the gambler in him!



For all his willingness to bet that this hay-conditioner roller is without fault, this John Deere Inspector will take nothing for granted.

For, although every possible precaution is taken in production to make each part fit specifications perfectly, the work of this inspector is part of the John Deere system of quality control designed to prevent even the entrance of error. But the system does not apply alone to the checking and measurement of parts and assemblies. Raw materials, skills, and methods are also closely watched as part of this preventive "insurance" against an inferior product.

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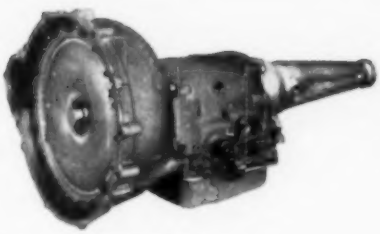

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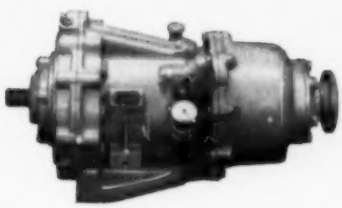

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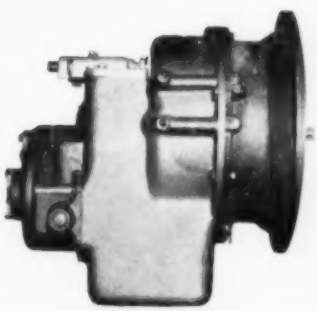

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Random Balance

Part II—Techniques of Analysis

THOMAS A. BUDNE*

Statistical Engineering Consultant, Great Neck, N. Y.

Editorial Note

Part I of this article began in the April issue of *Industrial Quality Control*. The article will be concluded in the June issue.

A Synthesized Illustration

The discussion of executing a designed experiment can best be built around a case history which appears as Part III of this article. The questions which arise are common to many industries and products.

The techniques of analysis, however, are best demonstrated in the following illustration which has been planned to include some of the complexities which have been found in a number of actual experiments. The data are synthetic, allowing us to create any desired conditions. In this way we can see how well the random balance experiment will achieve its objective.

We assume a manufacturing operation which has excessive variation. The nature of the problem is such that 12 variables or operating conditions A through L are the possible contributors to the problem. These variables or conditions may be either continuous or discrete. As continuous variables they may be: operating temperatures, pressures, speeds, rates of feed, rough dimensions, quantities of ingredients, lapsed time between operations, amount of moisture, humidity, hardness of cutting tools, etc. As discrete variables they may be: machines, technicians, operators, lots of raw materials, geometry of cutting tools, types of coolant, etc.

The objective of the experiment is to screen all variables to find the few which have major effects. The number and selection of levels to be programmed must be consistent with this objective. The excessive variation which constitutes the problem exists under conditions which are considered normal. Hence the experimental conditions must reflect normal operating conditions.

*The writer is indebted to members of the staff of Rath & Strong, Inc., with whom he was associated during the initial preparation of this article, for their valuable suggestions and criticisms.

The highest and lowest experimental levels must be equivalent to the experienced high and low values of the corresponding operating conditions. In statistical language, the 95th and 5th percentile values of the distribution of the recorded operating values of a variable would be ideal as the highest and lowest experimental levels of that variable. A smaller experimental range of a variable would fail to reflect its full contribution to the problem. A larger experimental range of a variable might exaggerate its contribution to a point where a minor effect is formed into a major effect. While it may be of interest to know that such a variable exists, it is not one of the major effects under the normal conditions in which the problem exists and is not one of the truly critical variables being sought.

It is no problem to establish the high and low levels in operations in which records of all operating conditions and variables are kept. When no records are available, a period of observation of the normal operations may serve to establish a good estimate of actual operating limits of the variables to be included in the experiment.

There is usually little value in going beyond two levels of each variable in a screening experiment. Exceptions will occur in the case of discrete variables which do not clearly have a high and low level. There may also be some feeling that particular continuous variables do not give a continuously increasing or decreasing response across their operating ranges and may, in fact, give extreme response only at some point within the operating range limits. While this condition may theoretically occur, experience in a large number of cases has failed to find such an occurrence. Normal operating ranges are usually too narrow to permit this phenomenon. Where the arguments in favor of an intermediate level are overwhelming, however, the intermediate third level may become necessary. The loss in simplicity of analysis as well as in ease of executing the experiment, justifies a strong effort to maintain only two levels for each variable.

The 12 variables in our assumed manufacturing operation are assigned two levels each. The variables are divided into two groups of six each and each group is programmed into a half-replicate of a 2^6 factorial design of 32 test runs. The two separate designs are detailed

TABLE VI—Variables Sub-Grouped in Half-Replicates of a 2^6 Factorial Design

First Group of Variables	A	B	C	D	E	F
Second Group of Variables	G	H	I	J	K	L
1	+	+	+	+	+	+
2	+	+	+	+	−	−
3	+	+	+	−	+	−
4	+	+	+	−	−	+
5	+	+	−	+	+	−
6	+	+	−	+	−	+
7	+	+	−	−	+	+
8	+	+	−	−	−	−
9	+	−	+	+	+	−
10	+	−	+	+	−	+
11	+	−	+	−	+	+
12	+	−	+	−	−	−
13	+	−	−	+	+	+
14	+	−	−	+	−	−
15	+	−	−	−	+	−
16	+	−	−	−	−	+
17	−	+	+	+	+	−
18	−	+	+	+	−	+
19	−	+	+	−	+	+
20	−	+	+	−	−	−
21	−	+	−	+	+	+
22	−	+	−	+	−	−
23	−	+	−	−	+	−
24	−	+	−	−	−	+
25	−	−	+	+	+	+
26	−	−	+	+	−	−
27	−	−	+	−	+	−
28	−	−	+	−	−	+
29	−	−	−	+	+	−
30	−	−	−	+	−	+
31	−	−	−	−	+	+
32	−	−	−	−	−	−

in Table VI. The two levels for each variable are designated as (+) and (−).

The sixth variable of each group has been confounded with the 5-factor interaction of that group. It can be seen that this is simply accomplished by assigning (+) or (−) to the sixth column as is indicated by the algebraic product of (+)'s and (−)s of the other five variables in that combination. Each of the 32 combinations in each of the two designs is now randomly assigned to test runs 1 to 32 in the first column of Table VII which gives the detailed design of the experiment.

The 32 synthesized test observations start with a random sample from a normal population having a mean of 100 and a standard deviation, $\sigma_0 = 2.0$. This sample appears under the heading Y_0 in Table VII. The following effects were introduced by adding them to the test results of the (+) levels of the indicated variables:

−15 to G

−12 to D

+10 to JK interaction

+8 to A

+6 to EH interaction

+4 to B

−4 to I

The data containing these added effects appear under the heading Y_1 in Table VII.

The contributed variance in each case is $E^2/4$ where E is the added effect.

The variance of the model, σ_T^2, becomes:

$$\sigma_T^2 = \sigma_0^2 + \Sigma \frac{E^2}{4} = 154.25$$

$$\sigma_T = 12.5$$

It will be noted that the sample standard deviation is 13.5.

The added effects were introduced to disperse strong main effects into both groups. One interaction lies wholly within one group while the other is split between both groups.

The analysis begins with 12 scatter diagrams. One for each of the variables (main effects) splitting the test results into the high levels and low levels for each variable. Figure 5 gives these 12 diagrams.

TABLE VII—Design of the Experiment and Processed Test Data

Test Run No.	Factorial Combination A-F	Factorial Combination G-L	Levels of Each Variable A	B	C	D	E	F	G	H	I	J	K	L	Test Results Y_0	Y_1	Y_2	Y_3	Y_4	Y_5
1	18	7	−	+	+	+	−	+	+	+	−	−	+	+	101	78	103	103	103	98
2	8	32	+	+	−	−	−	−	−	−	−	−	−	−	99	103	92	101	96	96
3	4	6	+	+	+	−	−	+	+	+	−	+	−	+	100	97	99	99	99	94
4	6	16	+	+	−	+	−	+	+	−	−	−	−	+	100	77	91	100	95	95
5	3	19	−	+	+	+	−	+	−	+	+	−	+	+	99	113	102	102	97	97
6	23	5	−	+	−	−	+	−	+	+	−	+	+	−	96	77	90	99	94	94
7	17	4	−	+	+	+	+	−	+	+	+	−	−	+	97	66	91	100	95	95
8	26	27	−	−	+	+	−	−	−	−	+	−	+	−	99	93	105	105	100	100
9	31	2	−	−	−	−	+	+	+	+	+	+	−	−	99	86	99	99	94	99
10	15	28	+	−	−	−	+	−	−	−	+	−	−	+	99	93	82	91	91	96
11	28	3	−	−	+	−	−	+	+	+	+	−	+	−	102	87	100	100	100	100
12	16	25	+	−	−	−	−	+	−	−	+	+	+	+	100	100	89	97	92	97
13	30	13	−	−	−	+	−	+	+	−	−	+	+	+	103	72	97	106	101	101
14	11	22	+	−	+	−	+	+	−	+	−	+	−	−	106	124	113	113	108	103
15	27	8	−	−	+	−	+	−	+	+	−	−	−	−	98	83	96	105	100	95
16	19	15	−	+	+	−	+	+	+	−	−	−	+	−	99	88	101	101	101	96
17	14	23	+	−	−	+	−	−	−	+	−	−	+	−	100	96	97	97	97	97
18	20	18	−	+	+	−	−	−	−	+	+	+	−	+	100	100	100	100	100	100
19	22	20	−	+	−	+	−	−	−	+	+	−	−	−	98	72	84	93	93	98
20	32	17	−	−	−	−	−	−	−	+	+	+	+	−	100	86	86	95	95	100
21	25	1	−	−	+	+	+	+	+	+	+	+	+	+	100	69	94	103	98	98
22	2	26	+	+	+	+	−	−	−	−	+	+	−	−	101	103	104	104	99	99
23	1	11	+	+	+	+	+	+	+	−	+	−	+	+	96	77	91	91	91	91
24	7	21	+	+	−	−	+	+	−	+	−	+	+	+	100	104	93	102	102	97
25	21	30	−	+	−	+	+	+	−	−	−	+	−	+	96	84	96	96	96	96
26	12	12	+	−	+	−	−	−	+	−	+	−	−	−	100	89	91	100	95	95
27	24	24	−	+	−	−	−	+	−	+	−	−	−	+	102	92	92	101	101	101
28	10	9	+	−	+	+	−	+	+	−	+	+	+	−	101	78	92	101	96	96
29	5	29	+	+	−	+	+	−	−	−	−	+	+	−	101	87	88	97	97	97
30	9	10	+	−	+	+	+	−	+	−	+	+	−	+	100	81	95	95	95	95
31	13	31	+	−	−	+	+	+	−	−	−	−	+	+	103	99	100	100	100	100
32	29	14	−	−	−	+	+	−	+	−	−	+	−	−	99	72	97	97	97	97
															Standard deviation	2.1	13.5	6.6	4.3	3.6	2.6

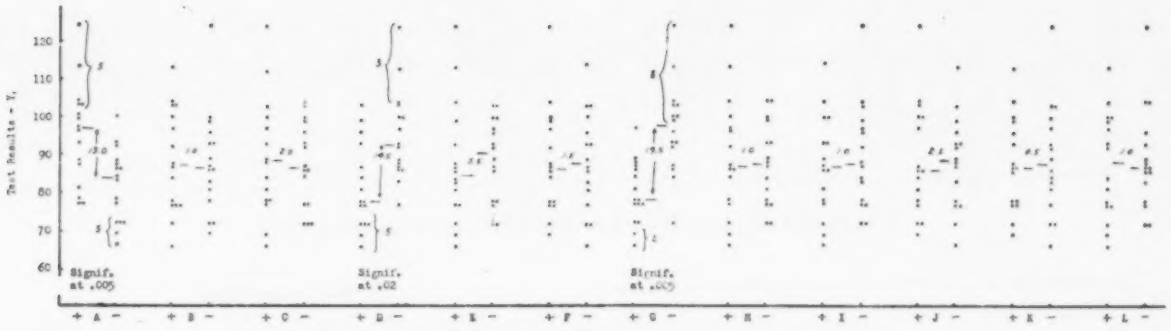

Figure 5—Scatter Diagrams for Main Effects Based on Original Test Data, Y_1

A very simple and rapid method for a first rough analysis is to mark the median location for each level of each variable and take the difference for the two medians of each variable. This is indicated in the diagrams. Since the data will appear to have "wild shots," this is a valid procedure and may even be theoretically superior to the use of arithmetic means, under the circumstances.

Clearly, the median differences for variables A, D and G stand out sharply. If a test of significance is desired, we may count the number of test results in the higher level which are higher than the highest test result of the other level and take a similar count for the low test results. Such counts are indicated in the scatter diagrams for variables A, D and G. The probability of getting a total of at least R such counted points with two groups of 16 points each is given by the statistic:

$$\frac{C_{16}^{32-R} + \sum_{r=1}^{R} C_{15-r}^{31-R}}{C_{16}^{32} - C_{15}^{30}}$$

Variables A and G each have a total of ten counted points. The computed probability of at least ten such points by chance alone is less than 0.005.

Variable D has a total of eight such counted points. The probability that R is at least eight is less than 0.02.

The general statistic which applies to any two groups of data of equal size is:

$$\frac{C_{n}^{2n-R} + \sum_{r=1}^{R} C_{n-1-r}^{2n-1-R}}{C_{n}^{2n} - C_{n-1}^{2n-2}}$$

where R is the sum of points counted at each end and n is the number of points in each group.

By the usual standards of tests of significance, differences which lead to probabilities of less than 0.02 and particularly 0.005, such as we find here, are real differences. The problems of multiple tests of significance are no different here than they may be in any other more classical situation. John W. Tukey* has recently presented a table for multiple comparisons between two groups of equal size, based on an "outer sum" (such as we have applied here in individual comparisons), at a five percent level of significance.

The application of such a non-parametric test is particularly appropriate when there may be reasonable doubt that we have a random sample of observations from a normal population. The existence of one or more questionable observations may seriously affect our right to use a "t" test.

We are now ready to remove the effects of A, D and G from our data, so that other effects may stand out more sharply. It is convenient and desirable to make the three corrections simultaneously. The data are laid out in $2 \times 2 \times 2$ factorial array as shown in Table VIII.

Totals and averages are computed in each box. The lack of exact balance could allow either D or G to effect the difference between A+ and A− averages. However, the procedure of averaging the averages of each box for a level average, removes this possibility. Thus,

the A effect is

$$\frac{(X_1 + X_3 + X_5 + X_7)}{4} - \frac{(X_2 + X_4 + X_6 + X_8)}{4} = +10.6$$

the D effect is

$$\frac{(X_1 + X_2 + X_3 + X_4)}{4} - \frac{(X_5 + X_6 + X_7 + X_8)}{4} = -11.87$$

the G effect is

$$\frac{(X_1 + X_2 + X_5 + X_6)}{4} - \frac{(X_3 + X_4 + X_7 + X_8)}{4} = -12.81$$

TABLE VIII—Analysis of the Effects of Variables A, D, and G

	D+		D−	
	A+	A−	A+	A−
G+	81 78 77 77 313 $\bar{x}_1 = 78.25$	78 72 72 69 69 357 $\bar{x}_2 = 71.40$	97 89 186 $\bar{x}_3 = 93.00$	88 87 86 83 77 421 $\bar{x}_4 = 84.20$
G−	103 99 96 87 385 $\bar{x}_5 = 96.25$	93 84 72 249 $\bar{x}_6 = 83.00$	124 113 104 103 100 93 637 $\bar{x}_7 = 106.17$	100 92 86 278 $\bar{x}_8 = 92.67$

$\bar{A}+ = 93.42$	$\bar{D}+ = 82.23$	$\bar{G}+ = 81.71$
$\bar{A}- = 82.82$	$\bar{D}- = 94.10$	$\bar{G}- = 94.52$
$\Delta A = 10.60$	$\Delta D = -11.87$	$\Delta G = -12.81$

*Presented at joint meeting of Institute of Mathematical Statistics, American Statistical Association and the Biometric Society at University of Pittsburgh, March 20, 1959. Publication is expected in a forthcoming issue of *Technometrics*.

Figure 6—Scatter Diagrams for Main Effects Based on Corrected Data, Y_2

The corrections to be made in the test data of column Y_1, are:

Add −11 to test results at A+ level

Add +12 to test results at D+ level

Add +13 to test results at G+ level.

The corrections were rounded off to the nearest whole number. The data thus corrected appear in column Y_2 in Table VII.

It is interesting to note here that the exact "t" tests on these variables would be:

A effect

$$\frac{(\bar{X}_1 + \bar{X}_3 + \bar{X}_5 + \bar{X}_7) - (\bar{X}_2 + \bar{X}_4 + \bar{X}_6 + \bar{X}_8)}{S_p}$$

B effect

$$\frac{(\bar{X}_1 + \bar{X}_2 + \bar{X}_3 + \bar{X}_4) - (\bar{X}_5 + \bar{X}_6 + \bar{X}_7 + \bar{X}_8)}{S_p}$$

G effect

$$\frac{(\bar{X}_1 + \bar{X}_2 + \bar{X}_5 + \bar{X}_6) - (\bar{X}_3 + \bar{X}_4 + \bar{X}_7 + \bar{X}_8)}{S_p}$$

AD interaction

$$\frac{(\bar{X}_1 + \bar{X}_3 + \bar{X}_6 + \bar{X}_8) - (\bar{X}_2 + \bar{X}_4 + \bar{X}_5 + \bar{X}_7)}{S_p}$$

AG interaction

$$\frac{(\bar{X}_1 + \bar{X}_4 + \bar{X}_5 + \bar{X}_8) - (\bar{X}_2 + \bar{X}_3 + \bar{X}_6 + \bar{X}_7)}{S_p}$$

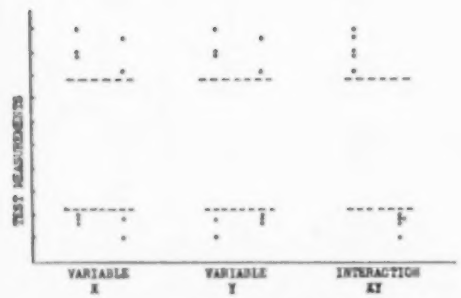

Figure 7—An Interaction Pattern

DG interaction

$$\frac{(\bar{X}_1 + \bar{X}_2 + \bar{X}_7 + \bar{X}_8) - (\bar{X}_3 + \bar{X}_4 + \bar{X}_5 + \bar{X}_6)}{S_p}$$

ADG interaction

$$\frac{(\bar{X}_1 + \bar{X}_4 + \bar{X}_6 + \bar{X}_7) - (\bar{X}_2 + \bar{X}_3 + \bar{X}_5 + \bar{X}_8)}{S_p}$$

where

$$S_p = S_w \sqrt{\Sigma \frac{1}{n_i}}$$

n_i = number of observations in each cell

S_w^2 = usual residual variance with $\Sigma n_i - 8$ degrees of freedom

The corrected data of Y_2 are now replotted in scatter diagrams as shown in Fig. 6.

This time variable C gives an effect of 7.5 which stands out sharply from all others. Its magnitude, however, is not of the same order as those of A, D and G already isolated. Further large effects among individual variables in the magnitude of ten units may exist among the interactions. It is then appropriate to examine the two-factor interactions for further large effects. This is done by forming a column which is the algebraic product of the (+)s and (−)s of the two variables whose interaction is to be examined and plotting the (+) level test result vs the (−) level test results for this product column. With 12 variables there are 66 two-factor interactions—a large number. The labor of isolating the few large effects can be reduced considerably. If an interaction has a large effect, it will probably give a run of (+)s at the top or bottom of the scatter diagram and a run of (−)s at the other end. (+)s can only occur if the original variables were both (+) or both (−). This means that a run of (+)s can occur only if both variables showed identical patterns at either the top or bottom sections of the diagrams. (−)s can only occur if the original variables had unlike signs. This means a run of (−)s can only occur if the two original variables showed mirror image patterns at the top or bottom of the diagrams. For example, see Fig. 7.

We examine the scatter diagrams for individual variables seeking those which are identical at one end and mirror images at the other. It is sufficient to start looking at the lowest three or 4 points and the highest three or four points. In Fig. 6, A with E, H and L are suspect at the lower ends. Of these only A with H and L remain suspect after examining the top ends. Examining B and then C and so on in turn with each of the variables which follow selects a relatively small group of suspects. A group of such suspect interactions has been plotted in Fig. 8.

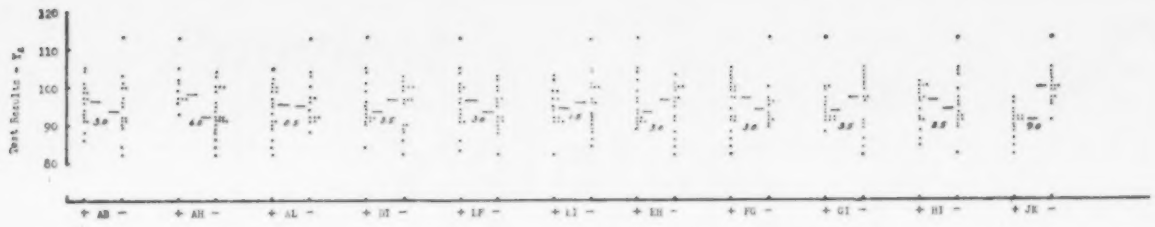

Figure 8—Scatter Diagrams for Selected Interactions Based on Corrected Test Data, Y_2

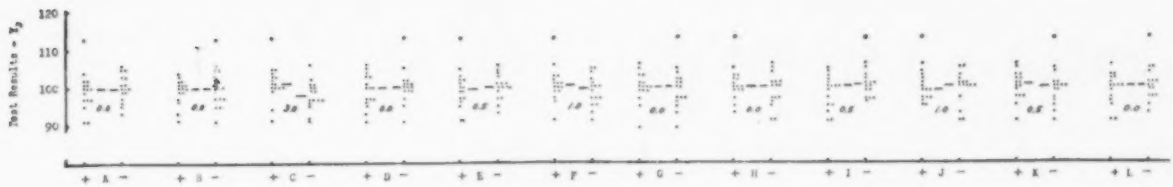

Figure 9—Scatter Diagrams for Main Effects Based on Corrected Test Data, Y_3

The AB interaction is the first combination of variables and is included only to show its appearance in graphical form. The JK interaction stands out clearly, followed by the AH interaction. We have then:

JK with an approximate effect of 9.0

C with an approximate effect of 7.5

AH with an approximate effect of 6.0

Since it is not possible to fill all the cells in a 2^3 array for JK, C, and AH, a 2^2 array for JK and C, the largest of the three effects, is presented in Table IX.

The effect of C is now only three units instead of the seven units indicated in the diagram. This may be due to the unbalanced effect of the eight units contributed by the JK interaction. Since an effect of three units is not clearly a real effect, we shall ignore it for the present and make corrections for the JK interaction alone. Plus eight (+8) units are added to the Y_2 results for which JK is (+) giving the corrected results in column Y_3 in Table VII.

The corrected test data of column Y_3 are again replotted in Fig. 9. Following the procedure outlined earlier, those variables which could be suspected as having two-factor interactions are plotted in Fig. 10. The EH interaction stands out sharply. C and the CG interaction rank second in importance, but again they may be only accidental. The analysis in the 2^3 table in Table X indicates an effect of approximately five for the EH interaction and questionable or no effects for C and for CG.

The test data of column Y_3 are corrected by adding −5 units to those test results for which EH is (−). The resulting corrected data are entered in column Y_4 of Table VII.

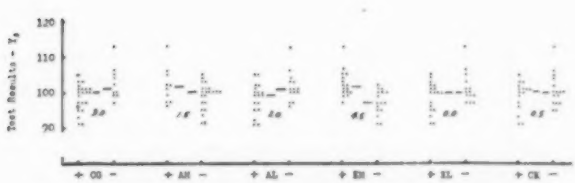

Figure 10—Scatter Diagrams for Selected Interactions Based on Corrected Test Data, Y_3

TABLE IX—Analysis of the Effects of C and JK

	JK+	JK−
C+	96 94 92 91 91 464 $\bar{x}_1 = 92.80$	113 105 104 103 102 101 100 100 99 95 91 1113 $\bar{x}_2 = 101.18$
C−	97 93 92 92 91 90 89 88 86 84 82 984 $\bar{x}_3 = 89.45$	100 99 97 97 96 489 $\bar{x}_4 = 97.80$

$\bar{C}+ = 96.99$ $\quad$ $\overline{JK}+ = 91.13$

$\bar{C}- = 93.63$ $\quad$ $\overline{JK}- = 99.49$

$\triangle C = 3.36$ $\quad$ $\triangle JK = -8.36$

TABLE X—Analysis of the Effects of C, EH, and CG

	G+		G−	
	C+	C−	C+	C−
$\overline{EH}+$	105 103 101 100 100 509 $\bar{x}_1 = 101.80$	106 100 99 99 404 $\bar{x}_2 = 101.00$	113 105 104 102 424 $\bar{x}_5 = 106.00$	102 101 97 300 $\bar{x}_6 = 100.00$
$\overline{EH}-$	103 101 100 99 95 91 589 $\bar{x}_3 = 98.17$	97 97 $\bar{x}_4 = 97.00$	100 100 $\bar{x}_7 = 100.00$	101 100 97 97 97 95 93 91 770 $\bar{x}_8 = 96.25$

$\bar{C}+ = 100.78$ $\quad$ $\overline{CG}+ = 99.70$ $\quad$ $\overline{EH}+ = 102.20$

$\bar{C}- = 98.56$ $\quad$ $\overline{CG}- = 99.64$ $\quad$ $\overline{EH}- = 97.14$

$\triangle C = 2.22$ $\quad$ $\triangle CG = 0.04$ $\quad$ $\triangle EH = 5.06$

Figure 11—Scatter Diagrams for Main Effects Based on Corrected Test Data, Y_4

TABLE XI—Analysis of the Effects of A, C, and I

	C+		C−	
	A+	A−	A+	A−
I+	99 97 96 95 95 91	100 98	92 91	95 94 93
	573	198	183	282
	$\bar{x}_1 = 95.50$	$\bar{x}_2 = 99.00$	$\bar{x}_5 = 91.50$	$\bar{x}_6 = 94.00$
I−	108 99	103 101 100 100 100 95	100 97 97 97 96 95	101 101 97 96 94
	207	599	582	489
	$\bar{x}_3 = 103.50$	$\bar{x}_4 = 99.83$	$\bar{x}_7 = 97.00$	$\bar{x}_8 = 97.80$

$\bar{A}+ = 96.88$ $\quad \bar{C}+ = 99.46$ $\quad \bar{I}+ = 95.00$

$\bar{A}- = 97.66$ $\quad \bar{C}- = 95.08$ $\quad \bar{I}- = 99.53$

$\Delta A = -0.78$ $\quad \Delta C = 4.38$ $\quad \Delta I = -4.53$

TABLE XII—Comparison of Actual Effects and Estimated Effects

Variable	Actual Effect	Estimated Effect
G	15	13
D	12	12
JK	10	8
A	8	11
EH	6	5
C	4	4
I	4	5

The corrected data, Y_4, are again replotted in scatter diagrams in Fig. 11 where the three largest indicated effects, A, C, and I, are analyzed in the 2^3 array in Table XI.

The appropriate corrections of 4 units for C and −5 units for I appear in the Y_5 column of Table VII.

It becomes evident in looking at the histograms of test results in Fig. 12 that the major sources of variation have been identified and very little more can be gained by further analysis. If further reduction in variation is pursued only for the sake of the challenge, it may even be possible to find that the corrections already made were not the most ideal corrections and that some effects of the corrected variables still remain. However, such a game is beyond the scope of the screening objective. The desired objectives were achieved. All the effects which were synthesized into the data were identified and their relative magnitudes were adequately estimated for all practical purposes. Table XII gives the estimated effects compared to the actual effects.

If the problem were one of optimizing the measured characters of the problem, more precise experimental designs, incorporating all the identified variables or incorporating some of them while the others are held constant, would be in order.

Editorial Note: Mr. Budne's article will be concluded in the June issue.

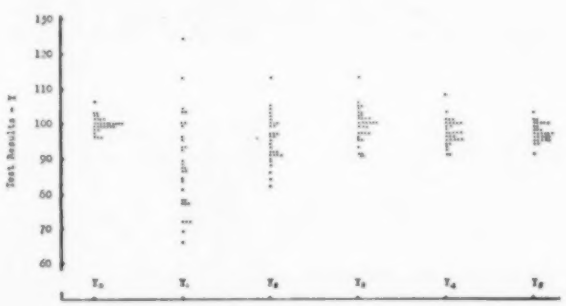

Figure 12—Frequency Distributions of Data at Each Stage of Processing

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Part II

J. Y. McCLURE

Convair, A Division of General Dynamics Corporation, Fort Worth, Texas

Editorial Note

Part I of Mr. McClure's article appeared in the April issue of *Industrial Quality Control*. The third and final part will appear in the June issue.

Statistical Applications to Process Control

The more a process is complicated with variables and other factors affecting the finished product quality and cost, the greater is the need for the application of statistical techniques for controlling the process. Quality degradations in a process are very difficult to trace to the source of trouble without a logical scientific analysis of the controlling factors. The goal of statistical control is to establish an ideal method for determining when trouble exists, the nature of the trouble, and a system for isolating and correcting the cause of the trouble; the latter is the main objective.

Process Control Techniques

In applying statistical techniques to the control of a process, three stages of application exist, each meriting consideration separately, but more so in combination:

1. Process Development Applications

The design and analysis of experimental data in the development stage of a process provide vital information for making more accurate conclusions with respect to the variables involved, and their influence on quality. At the same time, analysis of the data will suggest optimum operating levels for the variable characteristics involved. If the application in the initial development stage is overlooked, trouble spots often occur, resulting from insufficient information about the process.

Thus, there is little or no knowledge as to the source of trouble. Proper analysis of a process in the beginning will reduce considerably the number of problems occurring once a process is in operation.

2. Established Process Applications

After the development stage is completed and the process is in production operation, the application of statistical techniques is of particular importance in providing a system for indicating when a significant number of defective parts have occurred. After establishing the fact that sub-standard quality is being produced, the nature of the defects must be considered, since in most cases the type of defects determines in part the possible sources of trouble. Then comes the most difficult task, that of determining the exact cause of the defective parts.

3. Modification and Improvement Applications

After the process is operating efficiently and a method of control is established, investigations are usually made to determine where changes can be made in the process to reduce costs of operation and still maintain quality standards.

Statistical techniques can be used to an advantage in designing experiments and analyzing data to determine the effect of modifications of the process on quality and cost.

All statistical quality control case studies do not follow the above sequence, for many statistical programs are initiated after a process is in operation and trouble spots have developed. In these cases, the sequence of approach would be: (1) investigate procedures for controlling the process, (2) study previous development experimentation, and (3) recommend additional laboratory experiments if necessary.

General Quality Problems and Procedures

The following is an outline of a general procedure effective in approaching the task of statistical quality control application to a process:

1. Determine the Existence of a Quality Problem

A measuring device is needed to determine when to look for trouble and when to leave a process alone.

A controlled process is characterized by a certain pattern of variation clustering about a mean value. This variation is produced by a system of chance causes which are inherent in the process. Some of the chance cause variations may be eliminated or reduced, but it is neither economically feasible nor necessary since the product is sufficiently uniform in appearance and is acceptable without further improvement. The purpose of the measuring device is to distinguish between inherent process variation and variations caused by external, assignable causes which have entered the process. Corrective action is advisable only in the latter case.

A measuring device accepted and commonly used in most circles is the control chart for defectives, in terms of scrap and rework. Three situations can exist in a process: (1) the rework and scrap are at relatively low levels without erratic fluctuations, indicating minor if any quality problems; (2) the levels are moderately high with occasional peaks, justifying reasonable amounts of expenditure on quality improvement; or (3) the level of scrap and rework are exceptionally high, justifying extensive effort in reducing the amount of scrap and rework. To provide management with information as to when and where to exert pressure for quality improvement, the scrap and rework should be translated in terms of dollar loss attributable to the quality problems.

2. *Nature of the Quality Problem*

After determining that a quality problem does exist, the exact nature of the problem must be determined. Many aircraft plants have "Corrective Action Committees" or "Defect Analysis Teams" set up to study the nature of defects produced by a process. These committees attempt to locate and correct the cause of defects, and recommend responsibility charges. Usually, committee records will give the necessary data for analysis of the relative frequency of each of the types of defects to be segregated. This facilitates correlation of the variables of the process with the occurrence of defective parts.

3. *Causes of Quality Problems*

There are three factors which affect finished quality: (1) raw materials, (2) process variables, and (3) human element. The major task in determining the cause of quality problems is isolating the variables within these categories which affect finished quality, and then establishing control over these variables. Without the aid of statistical techniques and procedures, the study and isolation of processing variables affecting quality is extremely difficult.

The following are a few statistical techniques which are of value in aiding quality control of a chemical finishing or heat treating process:

a. **Experimental Design and Analysis of Data**

Heat treat or chemical processes are involved with a number of variables which affect finished-part quality. In a heat treat process, the various rates of heating and cooling, i.e., the temperatures, affect the physical quality of processed parts. Parts chemically processed are affected by the composition of the solution in the tanks, in addition to time and temperature variables. In determining the optimum operating levels of these variables and control limits within which these variables must be maintained in order to assure quality, properly designed and analyzed experiments are very helpful. They give measurable assurance of correct conclusions, with a minimum amount of expenditures.

b. **Correlation and Regression Studies**

It is sometimes possible, without recourse to extensive experimentation on a laboratory scale, to determine directly from production data how changes in process variables affect a response variable of a quality/cost character that is related in a dependent way on these process variables. Laboratory experimentation on a pilot scale often will not give a complete picture of a production process. Correlation and regression techniques provide a system for measuring the effect which the measured variables have on finished quality. This is helpful in determining control limits for the variables which are found to significantly affect quality.

Control Chart Analysis

A statistical technique effective in evaluating significant changes in variables is control chart analysis. This device facilitates the study of variation in raw materials entering a process, the composition of chemical processing tanks, changes in heat treat cycles, variations in detail parts going into sub-assemblies, and other process variables affecting quality.

d. **Comparison of Sets of Data**

Process modifications are sometimes attempted to reduce costs of operation, and/or improve product quality. A statistical technique useful for comparing effects of the modification relative to the previous process is available through statistical significance tests. Any difference between two procedures as they affect quality can be tested to determine if there is an actual difference or a difference due primarily to random variations.

Statistical quality control procedures and techniques have proven beneficial in aiding process control in many industries. The extent of their utility depends on the organization for the control of a process and the ability to obtain the necessary information for the statistical investigations.

Reduced Testing

Statistics is an effective management tool for reducing cost in testing and for controlling the product quality level.

1. *Reduced Testing, Example 1.*[*]

Quality control engineers are familiar with requesting information useful for testing a hypothesis. Equally important is the responsibility of recommending reduced testing when the expense is not justified, as in cases where excessive testing provides no additional quality assurance or useful information. Let us construct two hypothetical cases to illustrate this point.

a. Suppose rolls of bonded structure adhesive are received in approximately 300-ft. lengths and are tested for acceptance in several ways, including a tensile strength test of strips of metal bonded together with the adhesive.

One type, due to peculiarities in manufacturing processes, does not give consistent results when samples are tested from each end of the roll. Since there is a statistically significant difference, and very little correlation, both ends are tested to assure quality.

Now a graph is plotted with both A-end and B-end values superimposed on the same chart. It becomes obvious that the A-end, which has the

[*]Taken from actual case histories.

lowest average, is consistently below the B-end in individual values. In fact, two out of three rolls give lower values for the A-end, while the others are relatively close to the B-end values. This indicates that it is very unlikely for the B-end tests to cause rejection of a roll which is of acceptable quality by A-end tests. A recommended action is now made to eliminate the B-end tests. This will reduce testing by one-half, with a small risk in quality.

b. Suppose lap shear tests are made in clusters of ten specimens with the specification based on the average of the ten and the low value of the group.

The ten specimens are a continuous strip of material approximately 8 inches long and ½ inch wide cut from a roll 300 feet long. Obvously the variation found in this tested strip is not a good random sample of the roll. It is more a measure of testing variation.

It is desired to get information equivalent to that now obtained but with less testing. A smaller sample size will have more variation of averages from roll to roll but less opportunity to find low individual values and will apparently be a poorer estimate of quality.

Suppose the ten test specimens from 242 rolls of one type of tape, representing total purchases for one year, are chosen for analysis. For each roll, the average of the first five tests recorded, the average of the second five tests recorded, and the average of all ten tests are compared.* Statistical tests of significance are run on the three groups of samples, and it is determined that none of the three groups differ significantly in either averages or variation. The differences between the tests approximate a normal distribution. This indicates that a sample size of five can be substituted for the sample size of ten with only a small risk in quality and information.

Further examination determines that either of the two samples of five will fail to meet the specification more times than will the sample of ten, and will thus be a more critical measure of quality. Since individual tests fail their specification approximately one-half as often as do the averages, it is felt that the loss of opportunity for individual coupons to fail in the sample size of five is offset by the increased severity of the tests of averages. Suppose we finally note that only once does the test of ten show failure which the tests of five do not show, and even in this case, one of the samples of five did fail. This would enable us to recommend a reduction in testing, from ten samples to five.

2. *Evaluation of Processes, Example 2.*†

Evaluation of the process involved in the manufacture of the first few airplanes of a new design presents interesting problems. Suppose that hundreds of bonded panels, each to be bonded in a different tool, are required to make the first airplane. Since these panels will be heterogeneous in design and manufacturing methods, they will not, when combined, represent a single manufacturing process for which control limits or other analysis can be applied with confidence. Also, it becomes obvious that waiting for several of each panel to be bonded before beginning statistical control would allow millions of dollars to be spent without any benefit from statistics. We are aware that tools are often reworked, manufacturing techniques are improved, designs modified, etc. and that these too, will prevent the early formation of a homogenous universe. With so many uncontrolled (even unknown) variables, a casual relation could easily be misinterpreted as correlation.

a. One useful approach would be to plot the test results of all panels using one particular adhesive and ignoring all other variables. In this case, only well defined trends or cycles would be considered to be significant. These would be measures of the condition of the cleaning solutions and of the quality of the adhesive after aging during the storage period.

As various panels fail their tests, process analysts can begin investigation by determining if the failures are reflected in the trend of all panels or if they are unique to certain types. This information would be a valuable time saver in the early phases of the investigation.

b. Charts on the acceptance test values of rolls of adhesives can be used to check the vendor's manufacturing process. Suppose a series of panels fails, and apparently, the only factor they have in common is that they fail in the same time interval. The acceptance chart for adhesives can be used to plot the percent of production failures for each roll so that acceptance characteristics common to failing panels can be examined. Suppose in this case, the charts prove conclusively that no characteristic being tested is consistent to the failing panels. Chemists can then be assigned to search for other criteria in the adhesive.

This is an example of how correlation, showing that there is no relationship, provides useful information for guiding an investigation in the right direction.

3. *Measure and Report Results to Management*

Statistical programs, like all other programs, must be sold to management, and to gain proper recognition they must be evaluated in terms readily understandable to management. Communication to management is most effective when expressed in dollars or man hours.

Example 1, discussed previously, resulted in the reduction of one type of testing by one-half. This statistic does not describe the amount of saving and so should be expressed in other terms. By using further hypothetical data, the cost savings inherent in this reduced testing can be measured as shown in Table I.

Measuring Resultant Savings

By reducing the number of test tabs to be pulled for each bonding operation from ten to five, there would be a reduction in actual laboratory work of approximately twenty-three man hours per ship. There would also be a similar amount of reduction in actual test machine hours.

Suppose the tabulation indicates that there would be a savings of 483 man-hours and 483 test-machine hours, at 21 ship sets per month. These figures are based on 100 percent efficiency in production processes and 100 percent utilization of labor for testing. However, it is seldom that either of these factors will be at maximum performance.

*After the adhesive is cut, randomness requirements are met in regards to which small segment of the sample actually is used in any one of the ten tests.

†Taken from actual case histories.

TABLE I—Analysis of Savings Through Reduced Testing

	Spec. 131-1, Adhesive "XYZ"			Spec. 131-2, Adhesive "XYZ"		
	Time Expended	*Time Saved*	*Total Time Saved*	*Time Expended*	*Time Saved*	*Total Time Saved*
Present Testing						
(1) 10 lap shear tests per bonding operation.	0.90 hrs.			0.90 hrs.		
(2) Calculation time.	0.10 hrs.			0.10 hrs.		
Reduced Testing						
(1) 5 lap shear tests per bonding operation.	0.45 hrs.	0.45 hrs.		0.45 hrs.	0.45 hrs.	
(2) Calculation time.	0.05 hrs.	0.05 hrs.		0.05 hrs.	0.05 hrs.	
		0.50 hrs.			0.50 hrs.	
		×44			×2	
Total time saved per bonding operation multiplied by bonding operations per ship			22.0 hrs.			1.0 hrs.

In analyzing production efficiency, the bonding operations scrapped can be divided by the total number of bonding operations to determine the rate of scrap.

$$\frac{\text{Bonding operations scrapped}}{\text{Total number of bonding operations}} = \frac{321}{1448} = 22\% \text{ scrap}$$

Therefore, the total actual hours of 483 represents only 78 percent of the task, due to the scrap rate.

$$(483/78)\ 100 = 619 \text{ act. hrs. required}$$

Now the figure, of 619 act. hrs., represents 100 percent of the hours required, taking scrap rate into consideration.

However, let us assume that the efficiency in man hours is not 100 percent but instead approximately 80 percent. Therefore the total hours required (619) represents only 80 percent of the hours that will be needed for the task.

$$(619/80)\ 100 = 774$$

This final figure (774) represents the number of hours that can be saved per month with production at 21 ship sets per month.

Multiply this figure (774) times the wage rate, add in the overhead, and you arrive at a figure which represents the total savings as a result of reduced testing.

This figure is in terms of dollars. It is one which is recognized universally and of which management is very cognizant and appreciative.

Fabrication Quality Control

Departmental, Cost Center, and Work Station Control

A manufacturing industry may be composed of subdivisions which may be further divided into departments, cost centers, and work stations. A subdivision within a manufacturing industry is necessary in order to establish definite channels of communication, planning, operation, control of manufacturing processes, shop orders, for accounting payroll, personnel records and labor costs. This makes possible the determination of responsibilities and the assignment of specific duties to personnel within the department. Quality control based on these subdivisions is one phase of a controlled program.

An application tailored to a departmental, cost center, and work station level is helpful in increasing the effectiveness of a quality control program. The measured quality of manufactured products at this level does not have a great diagnostic value. Nevertheless, it is an extremely useful aid to production supervision in giving information as to when and where pressure should be exerted for quality improvement. This level of control will serve to point out troublesome areas which can then be diagnosed by control chart techniques. Attention can then be concentrated on the area or process where the largest cost saving in scrap or rework can be made.

The measuring of performance, the quality audit, in a fabrication department is usually based on two units of measurement, "Percent Defective" and "Avoidable Costs Per 100 Actual Hours Expended by Production Personnel." The percent defective data can be obtained from inspection records. The fabrication inspector can log the number of pieces inspected and rejected daily, by part number, on a "Daily Inspection Log Sheet." Rejected parts can be recorded on an "Inspection Rejection" or "Inspection Minor Rework Order" form. If the parts are dispositioned "Rework," the shop operator will list this rework time on this form after reworking the parts.

The "Avoidable Cost" data is usually based on three tangible costs generated by manufacturing; (1) Direct Labor Hours Expended in Rework, (2) Standard Hours Scrapped, and (3) Scrapped Material Cost. This type of audit defines performance in terms of economic impact. It permits the determination of troublesome areas and points out, in terms of dollars and cents, where the greatest savings can be made. Standard hours and the cost of material scrapped can be converted into actual hours, based on the cost of a production hour. These, together with rework hours, provide the basis for computation of a frequency of "Avoidable Costs Per 100 Actual Hours Expended."

The "Avoidable Cost" technique will be discussed more fully under the heading "Quality Audits for Management and Supervisory Control" in Part III.

Establishing Reliability of the Process and Products Through the Use of Statistics

1. Establish Inspection Criteria

a. Classification of Defects

This is the enumeration of possible defects of the unit of product classified according to their importance. A defect is any deviation of the product from specification requirement, contract, etc. Defects are usually grouped by definition into critical, major, and minor groups.[1] Definitions may vary among companies due to the difference in policies.

b. Coordination of C. D.'s and Shop Planning Paper

Serialized C.D.'s can be maintained in a permanent file in each inspection area. The serial number

of the C. D. should be entered on shop planning paper, opposite the inspection operation, to alert the inspector that planning exists and is to be followed.

c. Shop Use of Checking Tools

(1) The production worker should be provided with the same type of instruments (protractor, micrometer, vernier caliper, testing equipment check templates, check forms, etc.) that inspection uses to inspect parts. Thus the operator, applying in-process checking, assures that parts are being manufactured to specifications.

(2) First-part inspection often prevents the production of an entire lot of defective parts. Machined parts are inspected to assure that the machine has been correctly set up. Inspection on a sampling basis shall be continued during the remainder of the process to assure that parts continue to meet specifications.

The first part made on form dies is inspected to assure that the die meets all required standards. When inspection, production, and tooling personnel are assured that the tool is satisfactory, the quality control engineer is advised and a sample of 25 or more parts, depending on the size of the lot, is run for the purpose of establishing manufacturing capabilities of the tool. Close cooperation between the departments concerned is required to successfully accomplish this phase of the program. The simple technique used in determining machine and tool capabilities will be discussed fully in an actual case study in this section.

(3) By inspecting their own parts, the shop operators are assured that the machine or tool is producing good parts. This is quality control in its best sense—the *prevention* of defective parts. This method reduces rework and scrap costs and at the same time improves the quality of manufactured parts. If tools are found to be producing defective parts, production is stopped and the tool is processed for rework.

(4) After a form die is proven to be capable of producing good parts, the measured characteristics may then be inspected on an attribute basis.

2. Control of Tools and Fabricated Parts

a. The Analysis of Manufacturing Capabilities and Process Uniformity

Trouble is usually considered to be a common state of affairs in manufacturing. Whenever there is a high percentage of rejections for any of the many different parts fabricated in an aircraft company, there is a need for an examination of the reasons. The rejections may be due to the failure to meet dimensional tolerances. Shewhart control charts for variables are indispensable tools in the hands of a quality control engineer. These charts provide information in three categories, all of which should be known to determine a basis of action: (1) basic variability of the quality characteristic, (2) consistency of performance, and (3) average level of the quality characteristic. These charts, X and R, require actual measurement of dimensions.

The dimensions selected for control charts should be either those causing numerous rejections, having a high cost of spoilage and rework, or causing delays in assembly operations. Additional information derived through the use of X and R charts are:

(1) They indicate if the basic variability of the process is such that it is impossible to make all the product within the specification limits.

(2) They indicate when the need arises for a review of the specification limits.

(3) They provide information from which the process average can be derived. This average should be at an optimum level designed to meet the specification, but at the same time hold costs to a minimum.

(4) They can be used to determine the capabilities of machines.

(5) They indicate the presence or absence of assignable causes of variation.

But the important function of a control chart is to verify either that observed variations are random and require no action or to point out the time for investigation of non-random or assignable causes. The elimination of assignable causes, or "bringing a process under control," is responsible for much of the savings resulting from statistical quality control. (See Ref. 2-6 for additional sources of information on the X and R charts.)

b. Case Study of Joggled Parts

Control chart techniques which can be applied to any quality characteristics that are measurable, are very useful tools for analysis of manufacturing capabilities and process uniformity. The following example is an actual case study of a joggle dimension having a high cost of rework and causing delays in assembly. (See Fig. 4.)

The correction of one process will make parts meet specification, and eliminate the need for a hand form operation. This not only decreases production costs, but will also improve the quality of the product.

A sample size of 26 was available for this study. Readings were taken on each part at four designated locations through three processes: punch press, heat treat, and hand form. A dial indicator was used for measuring the height of the joggle area at the designated locations. Table II lists these values.

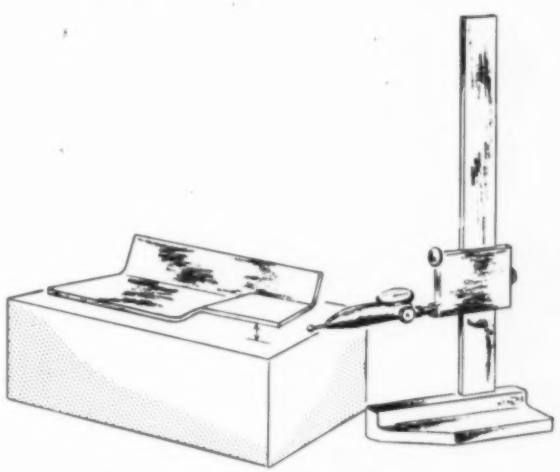


Figure 4—Part Studied for the Joggle Dimension

TABLE II—Individual Joggle Dimension Measurements of 26 Samples. Four Readings Made on Each Part at Designated Locations After Each of Three Processes

Sample No.	Punch Press				Heat Treat				Hand Form			
	1	2	3	4	1	2	3	4	1	2	3	4
1	0.078	0.067	0.081	0.078	0.070	0.064	0.077	0.074	0.072	0.076	0.072	0.079
2	0.076	0.070	0.081	0.079	0.074	0.065	0.078	0.075	0.071	0.075	0.071	0.077
3	0.076	0.068	0.078	0.076	0.072	0.064	0.076	0.073	0.072	0.071	0.070	0.072
4	0.077	0.070	0.082	0.081	0.073	0.065	0.079	0.077	0.073	0.074	0.073	0.081
5	0.079	0.070	0.082	0.081	0.074	0.065	0.079	0.077	0.075	0.076	0.073	0.080
6	0.078	0.070	0.082	0.081	0.075	0.066	0.080	0.077	0.071	0.074	0.070	0.076
7	0.077	0.071	0.083	0.082	0.075	0.066	0.080	0.078	0.072	0.080	0.076	0.085
8	0.078	0.070	0.083	0.081	0.075	0.066	0.081	0.077	0.070	0.070	0.068	0.073
9	0.077	0.070	0.082	0.082	0.075	0.067	0.080	0.078	0.074	0.077	0.071	0.079
10	0.077	0.069	0.082	0.081	0.075	0.067	0.080	0.078	0.070	0.071	0.070	0.075
11	0.078	0.070	0.084	0.082	0.076	0.068	0.081	0.079	0.074	0.077	0.078	0.082
12	0.079	0.069	0.084	0.081	0.076	0.067	0.080	0.078	0.074	0.077	0.074	0.082
13	0.076	0.066	0.080	0.077	0.075	0.066	0.078	0.074	0.070	0.074	0.072	0.080
14	0.077	0.068	0.081	0.080	0.076	0.066	0.081	0.079	0.071	0.074	0.074	0.080
15	0.075	0.068	0.082	0.080	0.076	0.068	0.081	0.079	0.069	0.071	0.071	0.074
16	0.075	0.070	0.083	0.081	0.075	0.067	0.081	0.078	0.073	0.078	0.071	0.080
17	0.076	0.067	0.082	0.080	0.077	0.067	0.081	0.078	0.070	0.076	0.071	0.078
18	0.076	0.067	0.081	0.079	0.075	0.066	0.079	0.077	0.069	0.076	0.067	0.075
19	0.076	0.067	0.082	0.079	0.076	0.068	0.081	0.079	0.068	0.077	0.072	0.082
20	0.074	0.068	0.051	0.079	0.074	0.067	0.079	0.076	0.073	0.079	0.073	0.083
21	0.076	0.067	0.080	0.079	0.073	0.065	0.080	0.077	0.071	0.071	0.074	0.079
22	0.075	0.069	0.080	0.077	0.075	0.068	0.079	0.077	0.072	0.081	0.076	0.089
23	0.076	0.067	0.082	0.079	0.077	0.068	0.081	0.078	0.073	0.079	0.073	0.081
24	0.076	0.069	0.080	0.077	0.076	0.067	0.078	0.074	0.071	0.078	0.070	0.081
25	0.075	0.067	0.081	0.079	0.075	0.066	0.079	0.078	0.070	0.079	0.071	0.082
26	0.076	0.069	0.082	0.080	0.076	0.066	0.081	0.078	0.071	0.076	0.074	0.083

The measurements at each location in each process should be identical and, ideally, all will be within specification limits after heat treat so that the hand form operation will be unnecessary. A detailed analysis of the average and variation of readings through the processes will show the changes necessary in the first operation to make a better part in the last operation. Table II lists the individual measurements in each of the three processes.

Figures 5a, b and c show the frequency distribution of the individual measurements, a total of 104 readings on the 26 parts through each of three processes. The average and variation from one individual measurement to another were compared to the specification limits. The "Lot Plot" method of tabulating frequencies was used.[7]

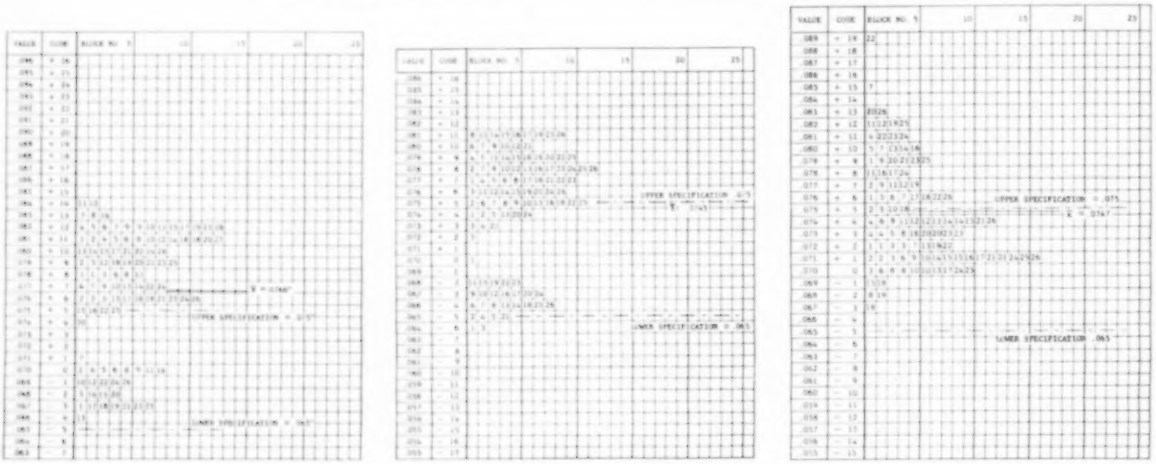
Figure 6 consolidates the frequency distribution charts showing a bar to represent the spread of actual individual measured readings. This figure illustrates the frequency distribution changes through each process.

Figure 7a shows by a bar the highest and lowest readings made on parts at each designated location through each process. The average variation and extent of variation that can be expected at each designated location is compared to the specifications.

Figure 7b illustrates the relation of each measurement to the other three as the part progresses through the processes. This relation is similar after punch press and after heat treat but changes after hand form. The purpose of the hand form operation is to correct the warping and bring all points within tolerance, but as can be seen it actually causes more variation.

Figure 5a shows a frequency distribution which appears to be bi-modal, with two clusters of concentrations. Such a condition may occur through chance, but is more likely to occur as the result of different series of data being combined. For example, measurements taken in one designated location vary considerably from measurements taken at another designated location. One meas-

Figure 5—Joggle Dimension Frequency (A) After Punch Press Operation, (B) After Heat Treat Operation, (C) After Hand Form Operation. Four Measurements Each of 26 Samples



(A) (B) (C)

urement from each sample varied 0.066 through 0.071 inches, and all others varied 0.074 through 0.084 inches. Figure 7a shows a significant variation in measurements taken at different designated locations.

Figure 5b shows no significant change in frequency distribution shape after heat treat. However, more dimensions conform to specification as the result of a downward shift in the process average. The process average shifted downward a little over 0.002 inches after heat treat.

Figure 5c shows the frequency distribution of 104 individual measurements taken on the parts through the hand form operation. There is an upward shift in the process average. This slight upward shift in the process average resulted in more of the dimensions exceeding the upper specification limit and fewer exceeding the lower specification limit.

Figure 6 consolidates the frequency distribution charts, showing a bar to represent the spread of actual individual measured readings. This figure makes it easier to see how the frequency distribution of the measurements change through each of the processes.

Less of the individual measured readings conform to specification after heat treat than after hand forming. Figures 5b and 5c show that only 46 or 44.23 percent of the readings were within specification after heat treating compared to 64 or 61.54 percent after hand forming. The average range of measurement after heat treating was 0.0133 inches compared with 0.0087 inches after hand forming.

Figure 7a shows by a bar the highest and lowest readings of actual measurements made at each of the four separate designated locations through each of the three processes. The process average and expected process spread is also shown for each designated location of measurement.

This figure shows four separate distributions which indicate that the tool has an excessive amount of variation, from 0.0686 to 0.0817 inches or 0.0131 inches compared with specification tolerance of 0.010 inches. The expected process spread of *each* distribution through heat treat does not

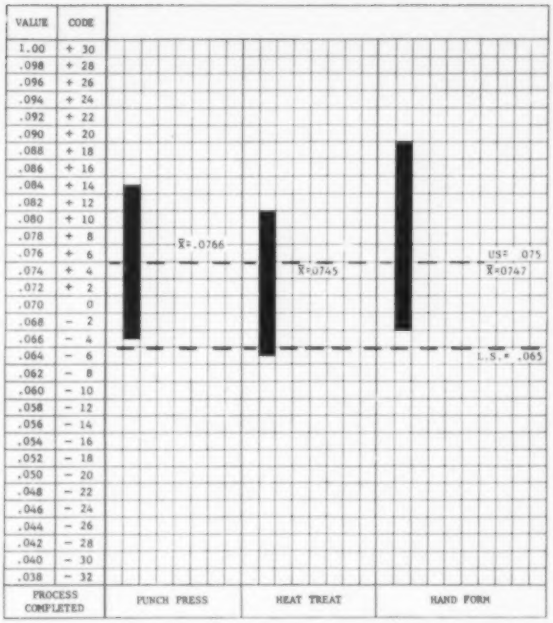
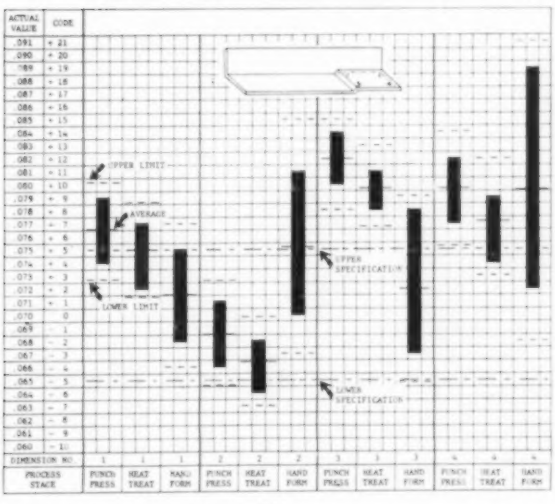


Figure 6—Consolidated Measurements of Joggle Taken After Punch Press, Heat Treat and Hand Form

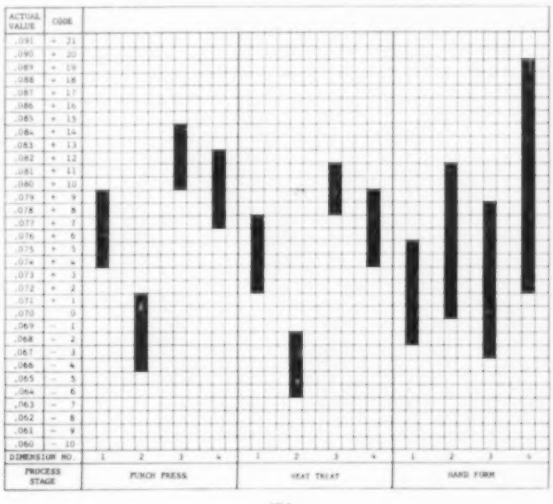
exceed the spread of 0.010 inches allowed by specification. The grouping of these four separate distributions into one resulted in the bi-modal and greatly skewed distributions as shown in Figures 5a, b and c.

Figures 7a and 7b indicate that parts can be made to meet specifications, without the hand form operation, if the "Punch Press Joggle Die," number 163919, is redesigned to center the process averages of designated locations of measurements to specification after heat treat. The basic variability of the punch press operation at designated locations of measurement is such that the natural tolerance range is less than the allowable tolerance range of specification. The process averages decreased approximately 0.002 inches after heat treating. If parts were heat treated prior to the joggle

Figure 7—Range of Joggle Dimension Arranged (A) by Each of Four Measurements and (B) by the Three Process Stages



(A)



(B)

operation, they could be made to meet specification provided the die is designed to center the process average of each designated location of measurement to specification.

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Editorial Note: Mr. McClure's article will be concluded in the June issue.

Graphical Diagnosis of Interlaboratory Test Results

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Introduction

Interlaboratory or round robin programs to evaluate the performance of test procedures will always be with us. New materials require new tests. New, and hopefully better, test procedures are developed for old products. Test procedures are used to ascertain whether a product meets the specification set down for the product. A double problem confronts the producer. There is bound to be a certain amount of variation in his product. And there is bound to be variation in the test results made on a given sample of the product. The impact of the errors of measurement associated with the test procedure is obvious because half the tests made on a product that just meets specification will rate the product below specification.

Test Procedures and Production Costs

It is customary to manufacture purposely a product that exceeds specification in order to allow for testing errors. The larger these testing errors, the greater the excess quality that must be built into the product to insure the acceptance of nearly all lots that are in fact equal to or better than the specification. The manufacturer already has to contend with variation in the process. Considerable saving in manufacturing costs can be affected by reducing the margin between the quality level set for production and that called for in the specification. The savings attainable with improved test procedures are a strong inducement for the improvement of test procedures. Interlaboratory test programs of varying degrees of thoroughness are frequently used to establish the performance of existing procedures.

Missed Opportunities in Interlaboratory Test Programs

Strangely enough modern statistical tests such as the analysis of multifactor studies and the isolation of components of variance have not made the contribution expected of them. Part of this no doubt comes about because these more sophisticated statistical techniques are not too well understood by some of those in the laboratories that run the tests. It is all very well for someone with statistical skill to set up an intricate interlaboratory test program and analyse the data but this still leaves the problem of interpreting the statistical jargon to those directly concerned. Even when this interpretation is undertaken the report is apt to read somewhat along these lines. "Duplicates run by the same operator in the

same laboratory show excellent agreement. Agreement between different operators in the same laboratories is not quite so good, and very poor between results from different laboratories. Results on different days do not agree as well as those obtained on the same day." This is a brief summary of the interpretation that is made after the statistical analysis shows that practically all the F-tests are significant. Unhappily almost all concerned were already aware of the state of affairs just described and want to know what can be done to improve matters. It is just here that statisticians have not risen to the opportunities presented by interlaboratory test programs.

When all is said and done, what we want is rather simple. We want to know whether the test procedure as set forth is capable of yielding acceptable agreement among results from different laboratories. If the results are not acceptable, we would like some specific indication of what is wrong with the procedure. If the procedure appears to be reasonably good but there are some disturbing discrepancies, we would like to know which laboratories are having trouble and if possible why they are having trouble. And most important we should be able to get this information back to the laboratories concerned in such a form that the diagnosis is believed. For only so will these laboratories take any action to correct the difficulties.

Graphical Representation of Results

The graphical procedure is based upon a very simple interlaboratory program. Samples of two different materials, A and B, are sent to a number of laboratories which are asked to make one test on each material. The two materials should be similar and be reasonably close in the magnitude of the property evaluated. This will avoid complications that may arise from differential behavior of the two test materials. A second pair of samples are circulated at a later time if there are only a few participating laboratories. The pairs of results that are reported by the laboratories are used to prepare a graph.

The graph is prepared by drawing the customary x-axis at the bottom of the paper and laying off on this axis a scale that covers the range of results for material A. At the left the y-axis is provided with a scale in the same units that includes the range of results reported for material B. The pair of results reported by a laboratory are then used to plot a point. There will be as many points as there are reporting laboratories. After the points are plotted a horizontal median line is drawn parallel to the x-axis so that there are as many points above the line as there are below it. A second median line is drawn parallel to the y-axis and so placed that there are as many points on the left as there are on the right of this line. Figure 1 shows the seven-day tensile strengths reported by 25 laboratories on two cement samples. Two of the laboratories are so patently separated from the other 23 that they are not used in determining the position of the median lines.

Diagnosis of the Configuration of Points

The two median lines divide the graph paper into four quadrants. In the ideal situation where *only* random errors of precision operate the points are expected to be equally numerous in all quadrants. This follows because plus and minus errors should be equally likely. In any existing test procedure that has come to my attention the points tend to concentrate in the upper right and lower left quadrants. This means that laboratories tend to get high results on both materials or low results on both materials. Here is evidence of individual laboratory

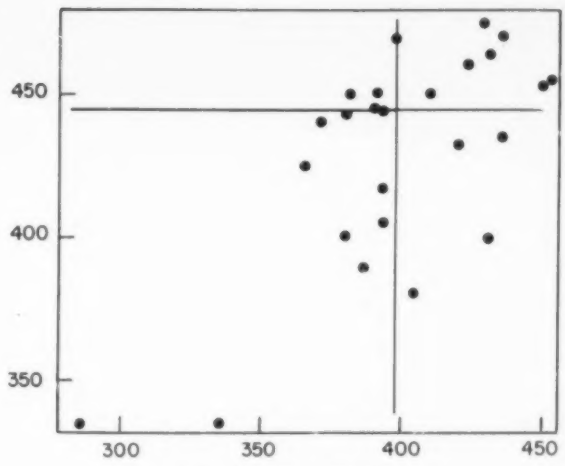

Figure 1—Tensile Strength

biases. There is evidence of this state of affairs in Fig. 1. The more pronounced this tendency to individual bias the greater the departure from the expected circular distribution of points about the intersection of the median lines.

Figure 2 shows 15 points plotted from phthalic anhydride determinations on two paint samples. The points tend to scatter more or less closely along a line approximately bisecting the upper right and lower left quadrants. There is reason to expect the line to make a 45 degree angle with the axes when the same scale is used for both axes and the two materials are sufficiently similar so that the dispersion of the results is about the same for each material.

A test procedure that yields results like those in Fig. 2 is probably in need of more careful description. In its present form the procedure apparently is open to individual modifications that do have an effect upon the results. The procedure rather than the laboratories should be considered as a possible source of the difficulty even though the difficulty is exhibited by a large scatter among the results from the different laboratories. When the points lie closely along the 45 degree line the conclusion may be drawn that many of the laboratories

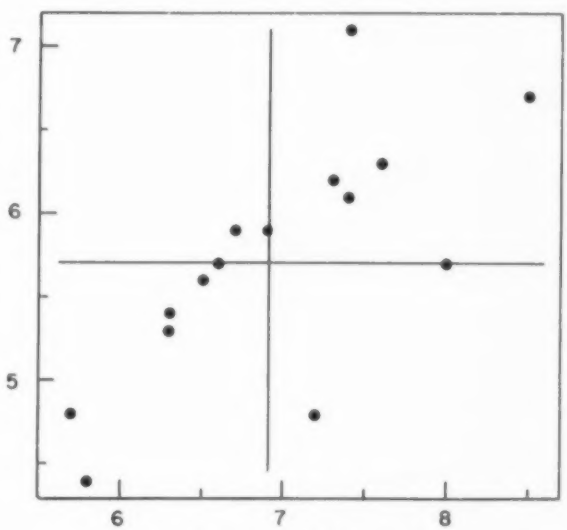

Figure 2—Percent Phthalic Anhydride

are following rather carefully their own versions of the test procedure.

Checking on Sample Variation

There is no possibility of the distribution of points in Fig. 2 arising from lack of uniformity among the samples distributed from each material. If the stock is heterogeneous, some samples will be high, some low, and this will be true for both materials. The pairs of samples distributed to the laboratories will be of four kinds:

high in A, high in B
high in A, low in B
low in A, high in B
low in A, low in B

The four possible combinations have the same probability of occurrence and would result in the test results being nearly equally divided among the four quadrants. Concentration of the points in two quadrants rules out questions of sampling heterogeneity.

On the other hand if there is a roughly circular distribution of points but with a disappointingly widespread scatter, the diagram does not reveal whether this arises from sampling difficulties or poor precision of the test results. If sampling is considered a possible source of difficulty the following modification in the assignment of samples should be tried. If there are 2N laboratories, prepare N *double-size* samples for each material. Carefully mix and divide each double-size sample into two usual size samples.

Double size sample	Laboratory	Samples A	Samples B
1	1	1A	1B
	2	1A′	1B′
2	3	2A	2B
	4	2A′	2B′
N	2N−1	NA	NB
	2N	NA′	NB′

The samples are assigned to laboratories as shown above. It should be possible to mix and divide each double-size sample into two closely matching regular samples. These samples are assigned to a pair of laboratories. If there are sampling difficulties the plotted points should tend to occur in doublets. Two laboratories getting the two carefully mixed halves should check each other and have their points close together. This involves a little extra work in getting out the samples and no extra work for the participating laboratories. If the points corresponding to the two halves of a double-size sample are separated as much, on the average, as points from different double samples, the dispersion cannot be ascribed to sampling. In addition to noting the spacial distribution the projections of the points on the axes may also be used to see whether just one of the materials was heterogeneous.

Interpretation of Out-of-Line Results

So far the large aspects of the diagram have been examined. The individual points can now be considered and in particular those points most distant from the intersection of the median lines. Almost always one or more points are so far out of the picture that it is better not to compress the scale in order to show them. Such points should be ignored in locating the median lines. (See Fig. 1.) The more distant points tend to fall into one or the other of two categories. Either the point is far out and remote from both axes or far out and fairly close to one or the other axis. In the latter case, the result is fairly good on one material and very bad on the other. Examples of such points are found in Figures 2 and 3. Often the explanation is simple—a mistake in typing, or calculation, or some simple blunder that sometimes can be corrected by going back to the records. If the same laboratory shows up in such a manner on succeeding pairs of materials, this implies carelessness on the part of the laboratory. The laboratory can do good work but often does not. Occasionally a laboratory has difficulty with one material and not with the other but this is not likely to occur with similar materials.

Points in the upper right or lower left quadrants that are far removed from the intersection of the median lines and that are not near either axis reflect a tendency to get either high results on both materials or low results on both materials. There are examples in all the figures. The more consistent a laboratory is in its work the more likely its point will lie in the proximity of the 45 degree line. A point far out along this line suggests the possibility that the laboratory concerned has introduced some modification into the test procedure. A laboratory finding itself in this situation should check carefully the prescribed procedure for performing the test and endeavor to locate the cause of the large bias.

All of the above interpretation can be made while keeping anonymous the identity of the plotted points. When circulating a report of the interlaboratory test it might be helpful to circle in red the point belonging to the laboratory in the copy going to that laboratory. That would save the laboratory from consulting its files to locate itself and would display prominently just where the laboratory stood in reference to the whole group. This vivid picturing of a laboratory's position should stimulate the laboratory to some self examination that could hardly avoid having beneficial results.

Estimating the Precision of the Test Procedure

The above discussion does not exhaust the information to be gleaned from this graphical representation. Assuming that the two materials are similar in type and nearly equal in magnitude for the property the dispersion among the results reported for A should be about the same as the dispersion of the B results. In that event the 45 degree line through the intersection of the medians makes possible an estimate of the *precision* of the data. Often an interlaboratory test undertakes to differentiate among the laboratories in respect to precision. Not only does this require large numbers of measurements from each laboratory but differences in precision usually turn out to be unimportant in comparison with bias errors and careless errors. No violence at this stage seems to be done by assuming about the same precision for all the laboratories.

The perpendicular distance from each point to the 45 degree line can be used to form an estimate of the precision. The estimate of the standard deviation of a *single* result is obtained by multiplying the average length of the perpendiculars by $\sqrt{\pi/2}$ or 1.2533. These perpendiculars need not be measured on the graph paper. Instead, write d wn for each laboratory the difference (A−B) keeping track of the signs. Call these differences $d_1, d_2, \ldots d_n$. Calculate $\bar{d}$, the algebraic average difference. Subtract $\bar{d}$ from each difference and obtain a set of corrected differences $d_1', d_2', \ldots d_n'$. The average of the absolute values of these differences when multiplied by $\sqrt{\pi/2}$ or 0.886 gives an estimate of the standard deviation.

TABLE I—Data and Calculations on Percent Insoluble Residue in Cement Reported by 29 Laboratories

Laboratory	Percent Residue		A — B	(A—B) — 0.095
	A	B		
1	0.31	0.22	0.09	—0.005
2	0.08	0.12	—0.04	—0.135
3	0.24	0.14	0.10	0.005
4	0.14	0.07	0.07	—0.025
5	0.52	0.37		
6	0.38	0.19	0.19	0.095
7	0.22	0.14	0.08	—0.015
8	0.46	0.23		
9	0.26	0.05	0.21	0.115
10	0.28	0.14	0.14	0.045
11	0.10	0.18	—0.08	—0.175
12	0.20	0.09	0.11	0.015
13	0.26	0.10	0.16	0.065
14	0.28	0.14	0.14	0.045
15	0.25	0.13	0.12	0.025
16	0.25	0.11	0.14	0.045
17	0.26	0.17	0.09	—0.005
18	0.26	0.18	0.08	—0.015
19	0.12	0.05	0.07	—0.025
20	0.29	0.14	0.15	0.055
21	0.22	0.11	0.11	0.015
22	0.13	0.10	0.03	—0.065
23	0.56	0.42		
24	0.30	0.30	0.00	—0.095
25	0.24	0.06	0.18	0.085
26	0.25	0.35		
27	0.24	0.09	0.15	0.055
28	0.28	0.23	0.05	—0.045
29	0.14	0.10	0.04	—0.055
Average	0.229	0.134	0.095	0.053

The data on percent insoluble residues reported by 29 laboratories are given in Table I and plotted in Fig. 3. There are three points far out along the 45 degree line and one far out on the y-axis. These laboratories were excluded from the calculations shown in Table I. The last column shows the differences between the two results diminished by the difference between the two sample averages. The average, 0.053, shown at the bottom of this column is the average of the *absolute* values, i.e., ignoring the signs. Multiplying 0.053 by 0.886 gives 0.047 as the estimate for the standard deviation of a single result. Probably this is inflated by leaving in the two laboratories turning in the very low results for sample A.

This estimate of the standard deviation for precision leads to the construction of circles (centered on the intersection of the median lines) within which any given percentage of the points can be expected to fall should the laboratories be able to eliminate all bias or constant errors. The multiples of the standard deviation that include various percents of the points are given in Table II.

Thus a circle whose radius is about 2.5 to 3.0 times the standard deviation gives a fair idea of the smallest circle that could be expected to contain nearly all points after the elimination of the constant errors that are causing the points to congregate in the upper left and lower right quadrants. Generally a fair number of points will lie outside such a circle. The laboratories responsible for these points almost certainly have somehow got substantial systematic errors incorporated in their techniques. Multiplying the standard deviation obtained above by 2.45 gives the radius of the circle that should include 95 percent of the laboratories if individual constant errors could be eliminated. This circle is drawn in Fig. 3. Seven further laboratories are outside the circle including the two who got the benefit of the doubt and were retained in the computation. This examination has directed attention to at least six of the laboratories that might well go over their method of making this determination of insoluble residue.

TABLE II—Probability Table for Circular Normal Distribution

Percent of the Points Within Circle	Multiple b of the Standard Deviation
10	0.459
20	0.668
25	0.759
30	0.845
40	1.011
50	1.177
60	1.350
70	1.552
75	1.665
80	1.794
90	2.146
95	2.448
99	3.035

Note: Percent $= 100[1 - \exp(-b^2/2)]$

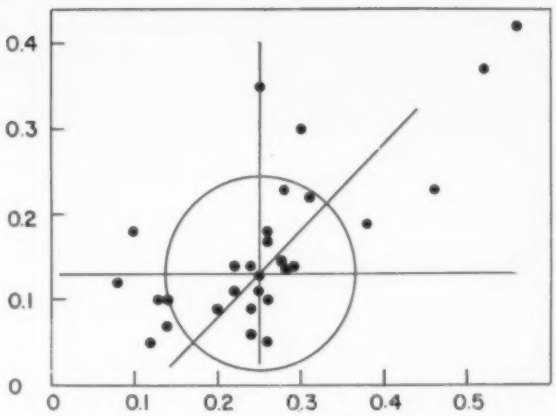

Figure 3—Percent of Insoluble Residue

If the number of laboratories in the program is rather small, the way to accumulate more points is to send the laboratories additional pairs of samples from different materials. A chart is prepared for each pair of materials and the median lines drawn in. The charts are now superimposed so that the points of intersection of the median lines coincide and, of course, the median lines also. All points are then transferred to one sheet of paper with one pair of median lines. As there are only a few laboratories each can be assigned an identifying symbol.

Figure 4 shows the reports made by eight laboratories determining CaO in cement. The laboratories are

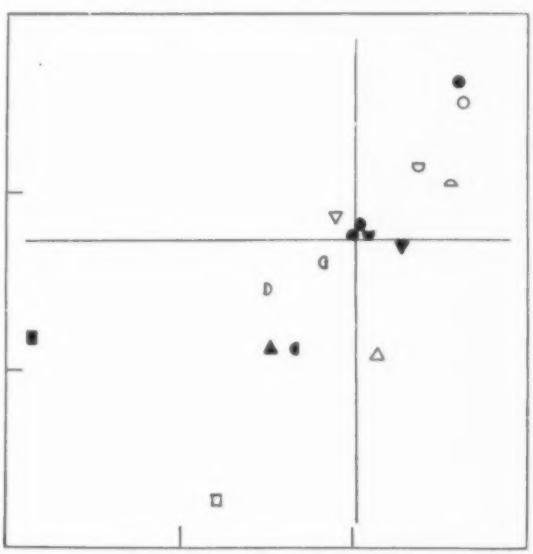

Figure 4—CaO in Cement (interval equals one percent)

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identified by symbols. The hollow symbols show the results for the *first pair* of samples. The corresponding solid symbols show the work of these same laboratories on a *second pair* of samples. Few as these data are they serve to indicate the things that we want to know about the test procedure and about the laboratories. Clearly this procedure is one that is vulnerable to individual bias. Two of the eight laboratories appear in the same region for both pairs. The circle laboratory is very consistent—and gets the highest results. The square laboratory gets very low results and is not very precise as shown by the fact that the two squares are separated by a much greater distance than any of the other seven pairs. Using this chart some possibly helpful suggestions could be passed along.

Discussion

The two materials used in this double-sample program were specified to be similar in type and in the magnitude of the property measured. Sometimes the measurement errors are proportional to the magnitude under measurement and this will show up in a greater scatter of the points along one of the axes. Particular types of samples may give trouble in just some of the laboratories. The thorough study of a test method must include consideration of these possible complications. Naturally a more comprehensive interlaboratory test program will be required to explore these aspects of the test procedure. A thorough study in one laboratory usually reveals these complications.

Summary of Advantages of Graphical Diagnosis

The double-sample, graphic analysis scheme described in this article offers a number of advantages.

(1) An unusually light burden is imposed on each laboratory

(2) The graphical procedure greatly facilitates presentation of the results in a convincing manner

(3) No statistical background is required to follow the reasoning and no computations are required to demonstrate the general presence of constant errors and the gross deviations of individual laboratories

(4) A minimum of computation is imposed upon the individual collating the results

(5) The use of a circle of 2.5 or 3.0 σ radius shows the individual laboratories whether or not their method of carrying out the test has in some way become saddled with a substantial constant error

(6) Most important the direction for improvement is clearly indicated

a. A long, narrow ellipse directs attention to a more careful description of the procedure or even to the need for modification

b. Wild points far out near either axis indicate erratic work

c. Wild points far out along the 45 degree line are strong evidence of substantial deviations from the specified procedure

d. General prevalence of constant errors is indicated by a substantial proportion of the points lying outside the 2.5 σ circle

Experience has already indicated that a certain few laboratories are found too frequently in the most distant positions from the intersection of the median. Improved performance from these few laboratories may go far to restore confidence in a test procedure. There is no substitute for careful work in the laboratory.

Design of Experiments *from a statistical viewpoint*

Part I

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Abstract

Quantitative identification of controlling factors can only be accomplished with tests keenly designed to make technically important differences stand out. Statistical concepts properly applied, allow the experimenter (whether plant or research man) to establish the significance and extent of each of the regulating variables with the fewest number of trials. Statistical planning anticipates the need for evaluating joint action among a large number of factors present in complex problems.

Part I of this article discusses, in an elementary way, test planning and the impact on experimentation of randomization, improvements due to grouping, and the interpretation of test trials. The advantages of replication of a factorial design in randomized blocks, Latin squares, Graeco-Latin squares, and Hyper-Graeco-Latin squares is considered. In Part II, which will appear in the June issue, an example is analyzed. A brief discussion of mathematical models is given in the appendix.

Introduction

When an experimenter asks a statistician for help in analyzing his data he is likely to find no relief at all in being told that the data can't possibly answer his questions. Yet this is not the fault of the statistician nor his methods, but rather that of the experimenter for running the wrong tests or for poorly stating his hypotheses. As Cochran and Cox[6] point out, the time to seek the statistician is *before* the experimental program is planned—not after. Just how does the statistician contribute to the success of an experimental program? The following discussion considers this four ways; by showing some of the ideas behind the statistical planning of experiments, by giving some examples of how to improve planning, by showing the effect of changing the "Designs," and by discussing how the experimenter can help the statistician and vice versa.

It is common to assume that the outcome of an experimental program has been achieved through the framework of the scientific method. However, there are times when other alternatives have influence. Cohen & Nagel[7] have identified several which may be summarized as follows:

1. **The Method of Tenacity** *(refuse to budge from your position—"no experimental work is necessary, from past experience we know that . . .")*
2. **Appeal to Higher Authority** *(cite results of an eminent scientist). Note that this can be overcome by:*
   a. becoming an "authority"
   b. "buying" the authority or
   c. citing a contradictory authority
3. **Method of Intuition** *("I feel it is so, hence . . . . ," or "Once you see the possibilities of this theory, you can see that it must be so.")*

However, the main difficulty is that not all people *feel* the same. There are often too many *opinions* and no way for an impartial judge to test them.

This has lead to *Reflective Inquiry*, or as it is called, the "Scientific Method." Stepwise, its approach is to:

1. Pose the problem as succinctly as possible
2. Form relevant theories or hypotheses to anticipate possible answers
3. State the alternatives
4. Ask what has been learned and what action should be taken if any of the hypotheses are true
5. Ask how these results will influence other results.

Once the principal hypotheses are set, attention can be focussed on the validation phase. The remaining steps are to:

6. Design a test of the hypotheses
7. Draw conclusions from the test
8. Revise, accept, or reject the hypotheses; and then repeat the procedure as needed.

By this method a procedure can be described so that it can be repeated by another experimenter independently.

Engineers may think the scientific method too formal for plant problems. Yet before their test programs can be adequately described, they must consider virtually the same questions as the research scientist. Systematizing the procedure makes the task less onerous. Most test engineers will find the following aids for test planning already part of their problem-solving approach.

*Presented at the All Day Quality Control Clinic, ASQC, Chattanooga, Tennessee, November 4, 1955.

Preliminary Planning

The points to be considered may be outlined* briefly as follows:

Statement of Objectives

a. Why the work is to be done
b. Consequences of failure to find improvements, or to claim them when they are not actual
c. A list of questions to be answered by the experiment
d. Experimental area to be covered
e. Time schedule
f. Allowable cost
g. Previous information or tests

Experimental Treatments

a. What is to be tested, how, and when
b. What the test result will mean; its compatibility with other work
c. Is the BEST among several sought, or the effect of a variable in a certain area, or the variation of several factors
d. Whether the study will be primarily empirical or contribute to fundamental knowledge
e. Which factors are initially considered most important; which least important
f. What extraneous or disturbing factors must be controlled, balanced or minimized
g. What kind of control is desirable
h. Whether the factors are independent or functions of other factors

Replication and Analysis

a. The number of tests to be done
b. What the experimental unit is and how it is to be replicated
c. Whether the replication is to be carried out all at once, sequentially, or in groups
d. How the data are to be statistically analyzed
e. Whether the accuracy and precision of the test method is known and in control

To answer many of these points five questions may help:

1. To be of *technical and practical importance*, how large must be the effects of the factors studied?
2. How much dispersion can be expected in the test results (all made under one set of conditions)? (Is it likely to be different at different levels of the factors?)
3. How many samples are necessary to minimize the risks involved? (From a cost standpoint, how many samples are allowable?)
4. What risk of failing to find an improvement of the size noted above can be tolerated?
5. What risk of claiming a significant difference, when none exists, can be accepted?

To illustrate two of the last points Table I shows the relative importance of spelling out the risk-protection needed. For example, if a wrong claim (α) is worth \$10 and a failure to find (β) is worth \$1000, the sensitivity of the test must be increased to provide a greater chance of reaching the correct decision. However, if positions are reversed and \$1000 will be spent if an improvement is claimed when none exists, but only \$10 will be saved if an improvement is found, then a different kind of protection is wanted.

It should be apparent that these decisions are engineering, business, or technical in nature rather than statistical. However, they influence later statistical choices. To see this, consider the part the statistician plays in planning experimental work.

*See Bicking[2] for a convenient checklist for planning test programs. Cochran and Cox[6] have also pointed out the importance of careful planning. *(Editorial Note: All bibliography references will appear at the end of Part II in the June issue.)*

*The Role of The Statistician**

Briefly, the statistician takes the expectation of the scientist and converts it into questions that can be tested mathematically. Then statistical tests are selected and the number of experiments necessary to achieve the desired results advised. Finally, a description of how to arrange the experiments to maximize the information obtained within the experimental and economic limits imposed is prepared. After the tests are complete, the statistician *helps the experimenter interpret the results.*

Statistical Principles

From discussion with the statistician, the experimenter learns that:

1. Certain statistical arrangements and tests are "best," to choose others may be wasteful
2. Randomization helps to minimize the effect of extraneous factors on the experiment and is *essential* to proper statistical interpretation
3. Replication is used to verify results, and provide an estimate of experimental error
4. Balance takes advantage of the greater similarity within such things as batches, lots, heats, melts, etc., in contrast to the difference between them, to reduce overall variation.

Statistical Designs

An experimental "design" is one of many possible arrangements of the factors. Since different designs have different properties (such as the ability to measure joint response, minimum variance, minimum number of runs etc.) proper selection for a particular study depends on careful statement of the problem and awareness of the designs available. "Designs" of physical test layouts can be adapted to even the most complex situations, often getting two to five times as much information as thought possible from a given number of tests. Specifically, statistical designs can be thought of as ways to remove the effect of unknown or unwanted factors, ways to achieve the greatest information from the fewest tests, and ways to make each experiment self-contained, yet comparable to others.

Putting the Principles to Work

Imagine that your boss calls up and says:

"In our 'ABC' reaction, I want to evaluate the process improvement that might occur if we (a) increase the temperature, by itself, (b) increase the mixing alone, or (c) increase both of them together. Naturally, I want the results in a short time. We have four kettles in which you can make tests. We also have four batches of raw material with which to work, but you can only

*See also Box.[3, 4]

TABLE I—Nature of Test Interpretation Risks

"Can we expect Process B to give a 10 ton per month improvement over Process A"?

		TRUTH	
		No	Yes
Claim as a Result of Tests	No	ok	Fail to Find (β)
	Yes	Wrong Claim (α)	ok

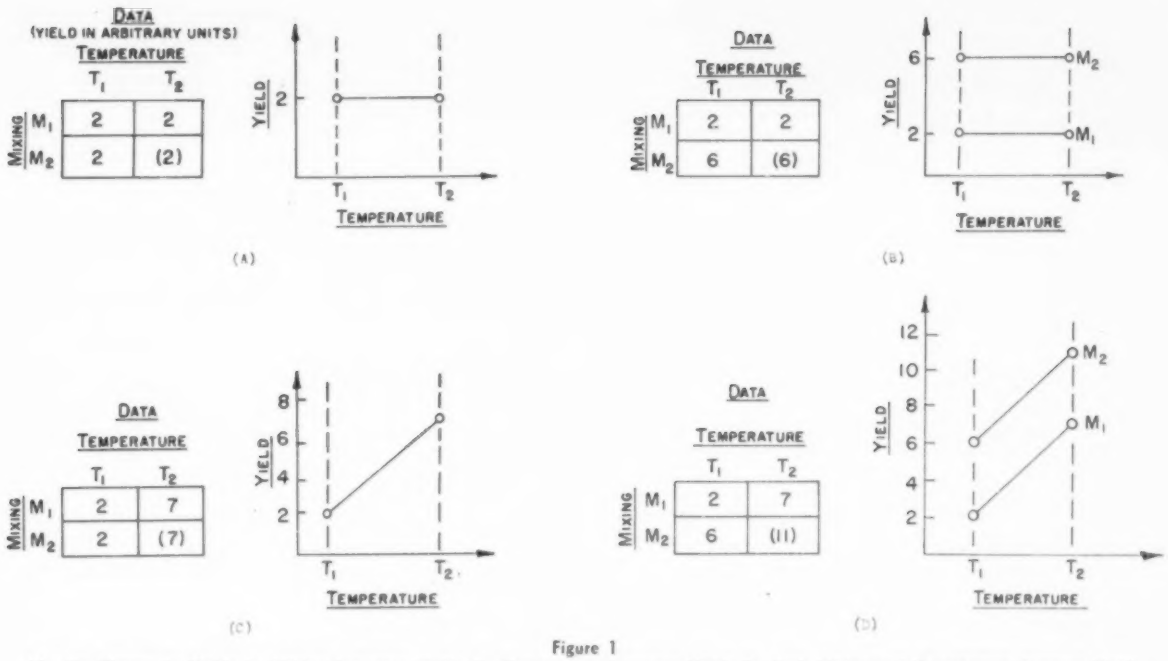

Figure 1
(A—No Change in Yield; B—Mixing Increases Yield; C—Temperature Increases Yield; D—Both Mixing and Temperature Increase Yield)

make four tests from each batch. I have no idea how much variation we will get in the process, nor do I have any notion how much improvement I would consider good. It would depend on its effect on other factors. I want a simple experiment that can be done fast. Have your recommendations in my office in the morning."

With the scene set, the first step in considering how to plan the experimental runs is to analyze the problem.

Step 1—Anticipate The Results

Ignoring how to use the batches and kettles momentarily, Fig. 1 shows what might be found if:

a. Neither mixing (M) nor temperature (T) increased the yield above its base level, two units (Fig. 1-A)
b. Mixing alone gave a four unit increase at both temperatures (Fig. 1-B)
c. Temperature alone gave a five unit increase regardless of mixing conditions (Fig 1-C)
d. Both mixing *and* temperature improved yield; mixing four units, temperature five units, for a total gain of nine above the base of two units (to a total of 11 units) (Fig. 1-D)

Note that the data in parenthesis ( ) represent test results predictable from the other data, provided only the above alternatives are possible.

A few experiences in which the factor effects are additive might lead to the belief that all combinations need not be tested. In fact, one strategy might evaluate one factor, then a second, separately. Figure 2 points out the danger of this type of testing, in which mixing speed is held constant while temperature is varied until a maximum is found; then at the selected temperature, mixing speed is changed and the effect noted. The "one-factor-at-a-time" approach is too time consuming when the factors act jointly. Also, note that such a plan can fail to find the "best" choices of M and T for maximum yield.

Figure 3 shows what might be expected when the factors reenforce, or nullify each other, respectively. In Fig. 3-A an increase in temperature causes a five unit yield increase when mixing is held at the same value, M_1. Also, increasing the mixing at temperature T_1 gives an increase in yield of four units (so far comparable to results in Fig. 1-D). However, when *both* mixing and temperature are increased, the net gain is 13 units rather than 9 as expected. The additional 4 units are attributable to synergism or interaction. The converse is shown in Fig. 3-B, in which increases in *both* factors give a much smaller increase in yield compared to expectation. If such results are found, to obtain maximum yield the levels of both mixing and temperature need to be specified. (In some situations an alert engineer can find a way to replace the two "interacting" variables with a different single variable.*)

Step 2—Use As Much Information As Possible

Since four kettles are available and are likely to be used later, including them in the experiment will broaden its base as long as any effect they may have

*See Box[1], [4] on "factor redundancy."

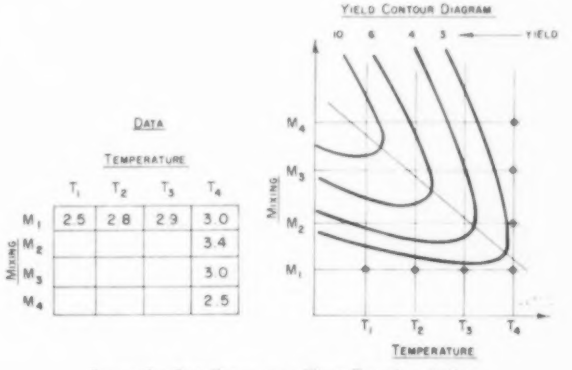

Figure 2—One Factor at a Time Experimentation

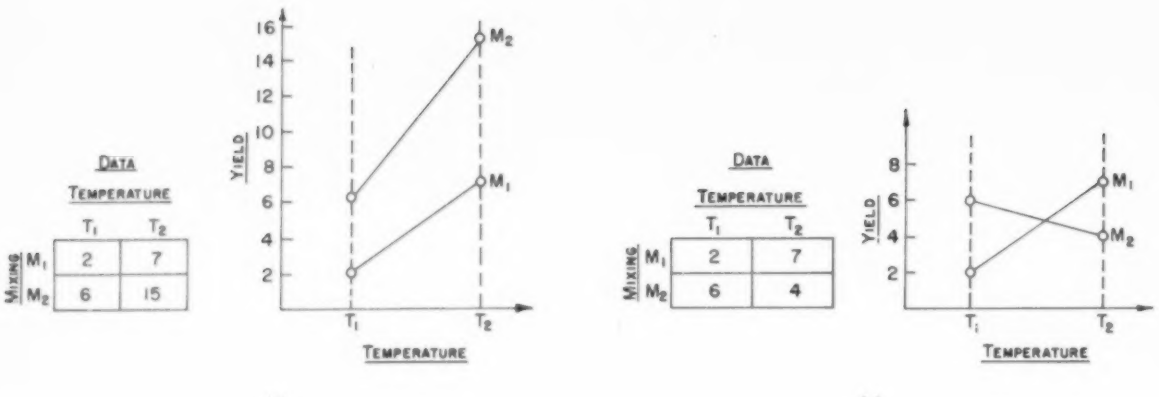

Figure 3 (A—Reenforcing Interaction; B—Nullifying Interaction)

will be separable in the data analysis. Also, their use will speed up the work. Likewise, the four batches may be included to see what effect raw material variation has on the process variables. Then the total number of tests possible will be 16. (Note the intentional introduction of processing variation into the experiment—in such a way that its effect can be assessed. While not all contingencies can be covered, "broadening the base" this way answers many questions at once that might not have been considered.)

Step 3—Select The Design

A "factorial" design* is preferred to study possible interactions. Since this is a preliminary experiment the variables may be limited to two temperatures and two mixing speeds. Hence, the total number of tests per replication of the entire experiment will be four. How to arrange the 16 tests can now be considered. The discussion will be limited to (a) Completely Randomized, (b) Randomized Block, (c) Latin Square, (d) Graeco-Latin Square and, (e) Hyper-Graeco-Latin Square experimental layouts.†

Table II describes the "shorthand" for identifying the experimental conditions for each test.

*A factorial design is one in which each factor is tested at all levels in combination with all levels of the other factors. Thus, if one factor is to be studied at N levels and another at M levels, N × M combinations will have to be run. Factorial designs have the property that the effect of each factor can be judged independently. (See appendix for an example.) See also references (1, 6, 8, 10, 11, 12) for additional information on factorials.

†In some situations the complete factorial design need not be done. See references (1, 2, 5, 6, 8.)

TABLE II—Single Replication Of The Test—Factorial Design

	Temperature		
Mixing	T_1	T_2	(1) is a test at M_1, T_1
M_1	(1)	t	
M_2	m	mt	t is a test at M_1, T_2, etc.

Skeleton Schedule For Performing Tests

	Batches			
Kettles	A	B	C	D
I				
II				
III				
IV				

Randomizing and Balancing

The general procedure for randomization is to assign the experimental "treatments" (m, t, (1) and mt) at random (using a table of random numbers) to the material under test. For example, if one analyst is to test eight specimens over eight days and it is suspected that there are differences among the specimens, each of the specimens is consecutively numbered from one to eight. Then, numbers are drawn from a random number table. The *order* the numbers are drawn decides which specimen is to be tested on the first day, second day, etc. Suppose the random numbers are 7, 3, 6, 2, 6, 1, 8, 3, 5, 7, 4. Then specimen #7 would be run on the first day, #3 on the second, #6 on the third, #2 on the fourth, #1 on the fifth (skip 6—it was already run), etc.

With a balanced design, such as the factorial shown in Table II, "double order" randomization can be used. That is, first, the material to be used for each run can be randomly assigned to the four treatments. Then, the *order* in which the test is to be carried out can be randomly set. By way of example, if four 50 lb. bags of raw material were needed and only three of supplier A and one of supplier B were on hand, two courses of action are immediately available: (1) blend all four bags together, rebag into 50 lb. bags and assign the four bags at random; or (2) assign the original four bags at random. Since randomization under plant conditions is frequently difficult to carry out, or tends to slow down the experimental work (and in some situations can actually introduce more variation in the results than it removes) it should be held to a minimum.

TABLE III—Completely Randomized Design
One possible assignment of tests to Kettles and Batches

	Batches			
Kettles	A	B	C	D
I	m	(1)	(1)	t
II	m	t	(1)	(1)
III	t	t	m	mt
IV	m	mt	mt	mt

A good review of the process will usually show at what stage randomization will be most fruitful. One thing is evident, it is necessary to prepare the randomized schedule for the plant supervisor rather than expect him to do it, to assure that it will be carried out. (It pays to have a statistically knowledgeable observer on

hand to answer questions or modify the schedule if necessary during the actual plant runs.) In some instances the plant supervisors may argue that randomized tests are uneconomical or will hold up production. Unless there are other ways to balance the design, a decision will have to be reached as to whether the value of the information to be gained will exceed the cost.

Completely Randomized Design

With a completely randomized layout the combination of test conditions is selected *without* regard to kettle or batch number and assigned to kettles and batches completely at random. This may be illustrated as follows: adopt some convention, such as filling the Kettle-Batch framework from left to right, top to bottom; put 4 (1), 4 (m), 4 (t), and 4 (mt) in a hat; mix well and pull out one at a time; record the results in the square. Table III shows one set of possible results. (If to be run this way, the test order could then be randomized as described above.)

Although this design will answer questions concerning the influence of mixing speeds and temperature on yield, it has certain drawbacks. If there is a difference among the kettles it could not be separated from the effect of the variables, mixing and temperature. The same is true of batches. Another objection is that three of the four tests being done with the first batch are *m*. Thus, if batches A and C had an adverse effect when used at M_2 and T_1, there would be no chance to learn the performance under other batches and an incorrect conclusion might be reached concerning the effect of mixing speed.

TABLE IV—Randomized Block Design
One possible randomization of tests to Kettles: Batches as Blocks

Kettles	Batches A	B	C	D
I	m	m	m	m
II	(1)	(1)	(1)	(1)
III	mt	t	t	mt
IV	t	mt	mt	t

Randomized Block Design

In this design, one element (kettles or batches) is chosen and a single replicate (m, t, (1), mt) arranged at random within this "block." The procedure is to choose one of the secondary factors, kettles or batches (whichever is expected to give larger differences externally). Call it "blocks." Then draw from a hat one at a time four slips of paper, one each labelled (1), (mt), (t), (m), to assign order of test within that block. Repeat for each of the other blocks. (In Table IV a convention was adopted such that the first selected treatment in each block would be done in kettle I, the second in kettle II, etc.) The disadvantage of this arrangement is that if batches had been chosen as blocks, it is possible to get all of one treatment (such as *m*) in one kettle (such as I). Again there is no chance to separate the effect of the kettle from that factor. (If all the experimental work was to be done in one kettle, the design could be adequate. But see below.)

Latin Square Design

An alternative choice is the latin square, in which the randomization is restricted so that each treatment appears the same number of times in each kettle and batch. To lay out the test, the randomization procedure starts with a "standard square" (see Ref. 6), arranges at random all 4 columns and the last three rows. Then the positions in the final square are numbered and the test order randomized. The treatments to be tested are those of the final square. (The subscripts in Table V show the test order.)

Advantages of the latin square include:

1. The ability to separate the effect of rows (kettles) and columns (batches) from the experimental error, thus permitting reduction of errors by skillful planning
2. Full use of all equipment and raw material for faster results

TABLE V—Latin Square Design*

Kettles	Batches A	B	C	D
I	t_{15}*	$(1)_5$	m_{14}	mt_8
II	m_9	t_{10}	mt_4	$(1)_{12}$
III	mt_2	m_{11}	$(1)_{13}$	t_{16}
IV	$(1)_1$	mt_6	t_3	m_7

*Test order completely randomized

3. More general inferences since more than one batch and kettle have been used with each treatment
4. The ability to test the effects of equipment and raw material, in addition to the treatments themselves.

Two limitations must be noted.[6, 13] The Latin square design assumes that the row and column effects (kettle and batch) do *not* interact with the treatment effects; thus, if any one kettle-batch combination does not affect each portion of the factorial experiment the same (that is (1), m, t and mt) the experimenter will be misled in his data analysis and interpretation.* The second difficulty is that enough batches and kettles must be available to form the square. When this is not possible, other designs may be used.

The experimenter does not always have freedom in deciding whether the tests shall be done one at a time or four at a time (the latter would speed up the work by using four kettles simultaneously). Even though the treatments have been assigned to kettles and batches in a Latin square, if the *order* of experimenting is *completely randomized*, as shown in Table V, test 1 must be completed *before* test 2 can start since they both use kettle IV. An alternative is to restrict the randomization to ordering the tests for each kettle separately. A typical result is shown in Table VI-A.

Graeco-Latin Squares

Although this procedure resolves the test order problem it creates another. Table VI-B shows the factorial treatments arranged in order of testing. Thus, test 1 in kettles I and IV will be (mt); each at high temperature

*This is also true of the design described later—the Graeco-Latin-Square and the Hyper-Graeco-Latin square.

TABLE VI—Latin Square Design
Order of Experimenting Restricted by Kettles

A

Kettle	Batch A	B	C	D
I	t_2	$(1)_3$	m_4	mt_1
II	m_3	t_1	mt_2	$(1)_4$
III	mt_2	m_1	$(1)_3$	t_4
IV	$(1)_4$	mt_3	t_2	m_1

B

Kettle	Order of Test 1	2	3	4
I	mt	t	(1)	m
II	t	mt	(1)	m
III	m	mt	(1)	t
IV	mt	t	m	(1)

and high mixing speed. For the same reason that the original randomized block design was discarded, this may be objectionable. For example, if the yield was increasing linearly with time during the day the tests were carried out because one of the reactants was warming up in a tank exposed to the sun, then three of the four tests carried out at M_1, T_1, (1) would show an increased yield that did not truly reflect the effects of mixing speed and temperature; all this solely because of the order of the test. The way around the problem is to further restrict the randomization, in the same manner the original Latin square was selected. The additional restriction puts a different factorial treatment first in each test in each kettle. Such a design is called a Graeco-Latin Square ("graeco" since Greek letters were originally used to designate the order of testing). Table VII shows one possible Graeco-Latin square.

Hyper-Graeco-Latin Squares

To avoid confounding the effect of kettle operators with treatments, the procedure can be carried another step further,* by the use of Hyper-Graeco-Latin squares. Table VIII-A shows the test layout in which each operator runs each treatment once in each order in each kettle with each batch. Table VIII-B shows the data sheet for the first eight tests in the order in which they would be carried out. It will be noted that test numbers 1-4 (the first done in each kettle) use each of the four operators, all the kettles, one part of each batch, and cover each treatment combination. The same will be true for successive groups of four tests.

Before examining an actual example, a comparison of the variance analysis for each of the designs seems appropriate to point out the reduction in the error term. This is done in Table IX. While fewer degrees of freedom for the error term usually mean lower sensitivity, when factors such as batches, kettles, and time of test have an influence, the more complex designs become more efficient due to the reduction of the experimental error sum of squares term. This is not always the case and power curves should be consulted in selecting the design and the amount of replication necessary. Note however, that the Hyper-Graeco-Latin square design requires replication of the square (all 16 runs) or an independent error estimate, as it has zero degrees of freedom for error.

*See Fisher[1935] and Brownlee[1] for further uses of orthogonal squares.

TABLE VII—Graeco-Latin Square*

Kettle	Batch A	Batch B	Batch C	Batch D
I	t^1_{β}	$(1)^2_{\gamma}$	m^3_{α}	mt^4_{Δ}
II	m^4_{γ}	mt^3_{Δ}	t^2_{α}	$(1)^1_{\beta}$
III	$(1)^3_{\Delta}$	t^4_{α}	mt^1_{β}	m^2_{γ}
IV	mt^2_{α}	m^1_{β}	$(1)^4_{\gamma}$	t^3_{Δ}

*Superscript indicates test order

TABLE VIII—Hyper-Graeco-Latin Square*

A—Test Layout

Kettle	Batch A	Batch B	Batch C	Batch D
I	m^1_{α}	t^2_{β}	mt^3_{γ}	$(1)^4_{\Delta}$
II	t^4_{γ}	m^3_{Δ}	$(1)^2_{\alpha}$	mt^1_{β}
III	mt^2_{Δ}	$(1)^1_{\gamma}$	m^4_{β}	t^3_{α}
IV	$(1)^3_{\beta}$	mt^4_{α}	t^1_{Δ}	m^2_{γ}

*superscripts = test order
letters = treatment
subscripts = operator for kettle for this test

B—Data Sheet

Test No.	Test Order	Kettle	Batch	Treatment M	Treatment T	Operator
1	1	I	A	2	1	α
2	1	II	D	2	2	β
3	1	III	B	1	1	γ
4	1	IV	C	1	2	Δ
5	2	I	B	1	2	β
6	2	II	C	1	1	α
7	2	III	A	2	2	Δ
8	2	IV	D	2	1	γ

TABLE IX—Degrees of Freedom for Each Design in Analysis of Variance

Variance Due to Differences Among:	Completely Randomized	Randomized Blocks	Latin Square	Graeco Latin Square	Hyper-Graeco-Latin Square
Mixing (M)	1	1	1	1	1
Temperature (T)	1	1	1	1	1
M × T Interaction	1	1	1	1	1
Batches		3	3	3	3
Kettles			3	3	3
Time of Test				3	3
Operator					3
Experimental Error	12	9	6	3	0
TOTAL	15	15	15	15	15

Editorial Note: Mr. Bingham's article will be concluded in the June issue.

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The Compatibility of Value Engineering Analysis and Reliability

RICHARD M. JACOBS

*Radio Corporation of America, Moorestown, N. J.**

VALUE ENGINEERING AND RELIABILITY are often thought to be in conflict with each other, a belief predicated on the basis that reliable design is expensive design. Indeed, justification for this expense is obtained by demonstrating the reduction in maintenance, installation, operation and logistic costs which result from improved equipment reliability. It is the intention here to demonstrate that the initial cost can sometimes be reduced by a value engineering analysis at the same time the reliability of the equipment can be improved. The compatability of value engineering and reliability is not a dream—it is a proven fact.

Value engineering analysis can be and is a tool for improving the reliability of equipment without necessarily reducing its initial cost. The converse is also frequently found to be possible.

Before we examine how compatible reliability and value engineering actually are, it may prove beneficial to discuss what these two terms mean to us in the electronic industry.

Reliability

Reliability can be defined as the probability of success or operation of particular equipment to perform its function as it was designed to do. This includes the environmental conditions under which the equipment operates, the time period the equipment is to operate, and the specific functional responsibility of that equipment. Reliability studies under this definition include consideration of such items as down-time, maintenance, marginal checking, modularization, human engineering, component part failure analysis, packaging, heat dissipation and a host of other items. It is therefore axiomatic that reliable equipment will have the degree of completeness required by the optimization of each and every characteristic that may affect the reliability of that equipment.

Value Engineering Analysis

"What does all this reliability cost?" is a common question heard among members of our industry and members of the military services. We are assessing these costs and value engineering analyses are being made to evaluate the function and its requirement for the expense involved. A value engineering analysis is defined as "an objective appraisal of all elements of the design, construction, procurement, installation, and maintenance of equipment, including the applicable equipment specifications, in order to achieve the necessary functions, maintainability and reliability of equipment at minimum cost."[5, 9] Thus value engineering is not simply cost reduction—it is an analysis of function versus cost.

Total cost is another way of expressing the definition. Total cost is made up of the initial or procurement; installation, operation, maintenance, logistic, replacement parts costs and the amount of time needed to install, maintain, and await the arrival of special parts not readily available. A VE analysis is a study of each operating function to determine its contribution to the overall worth of the equipment. Each characteristic is evaluated to optimize reliability and is reviewed to determine if modifications can be made that will substantially reduce the cost of providing that degree of operability, level of reliability, etc. which was originally thought necessary. Increased reliability is a natural by-product of equipment simplification—a VE analysis goal; hence it is an indication that VE and reliability go hand in hand.

Reliability Achievement

Reliability can be enhanced by many different yet specific and coordinated efforts. A few of these efforts are:

a. Reduce complexity of electronic systems
b. Reduce the number of parts in the system
c. Provide redundant circuits or assemblies
d. Include standby facilities
e. Use marginal checkout techniques
f. Reduce maintenance time by modularization, easy location of test points, built-in or wire-in test apparatus
g. Improve component life
h. Improve use of components
i. Standardize circuits, parts and assemblies
j. Install environmental controls
k. Train higher skilled maintenance personnel
l. Schedule periodic maintenance

*Mr. Jacobs is now supervisor of reliability engineering with Sylvania Electronic Systems, a Division of Sylvania Electric Products, Inc., Waltham, Mass. He was affiliated with RCA at the time the article was prepared.

VALUE IMPROVEMENT

HOW DO WE DO IT?

1. We help everyone concerned appreciate the need for improvement.
2. We organize to do the job.
3. We set goals.
4. We develop *cost prevention* techniques and train ourselves to use them.
5. We develop *price prediction* aids as an important tool in meeting our goals.
6. We continue to improve and use our *cost reduction* techniques.

The work falls into three areas, with equal responsibility for action delegated to:

ENGINEERING . . . VALUE ENGINEERING. Optimum simplicity and lowest cost for required performance.

PURCHASING . . . VALUE ANALYSIS. Better value parts, materials, and sources.

PRODUCTION . . . METHODS IMPROVEMENT. Development of improved fabrication and assembly processes and values.

Figure 1

VALUE IMPROVEMENT TESTS

These tests are guides to better value. In the selection and application of parts, materials, and processes . . .

HAVE YOU

1. Challenged specification requirements?
2. Eliminated unnecessary parts or functions?
3. Simplified the design as much as possible?
4. Made maximum use of standard items?
5. Used least costly materials?
6. Designed for lowest manufacturing cost?
7. Relaxed tolerances as much as possible?
8. Used lowest cost finishes?
9. Used company Material and Component Specialists?
10. Fully utilized Purchasing's assistance to gain suppliers' "know-how"?

Figure 2

CRITICAL VALUE IMPROVEMENT TECHNIQUES

The following techniques have been developed and proven by experience:

Get ALL the FACTS . . .
Use the BEST SOURCES for information . . .
Be SPECIFIC and omit generalities . . .
Evaluate design by COMPARISON . . .
Consider the FUNCTIONS of every part . . .
Make use of SPECIALTY products, materials, and processes . . .
THINK CREATIVELY . . .
Be completely OPEN-MINDED to new ideas . . .
Weigh DOLLARS against each MAJOR IDEA . . .
Use STANDARD PARTS AND MATERIALS . . .
Use COMPANY SERVICES . . .
Employ your OWN JUDGMENT . . .

Figure 3

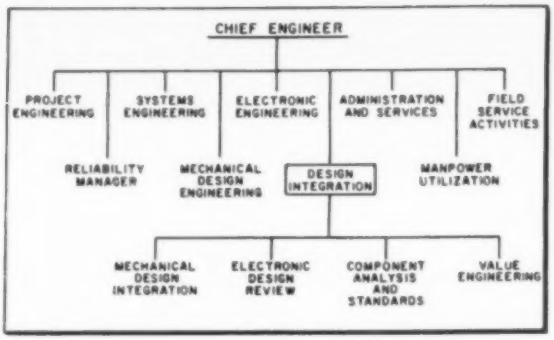

Figure 4—Organizational Chart of Missile and Surface Radar Engineering

m. Prepare better instructions on operation and maintenance
n. Perform system operation analyses.

In some, initial costs will be reduced, in others, such costs will increase. Where the initial cost is increased, it must be justified by reductions elsewhere or substantially improved reliability.

Reliability Program

At RCA the reliability program has been a management function these past six years. We have instituted

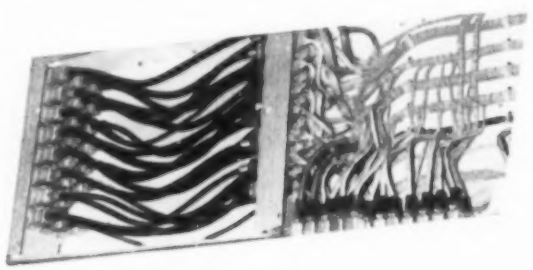

Figure 5

various concepts and techniques used in the prediction, measuring and evaluating of our equipment reliability. The organization depends heavily on design reviews,[10] standardized parts and circuits, feedback of information derived from failure reports, and the analyses of the mechanisms of failure to provide more reliability in our equipment. The reliability program is an integrated function of all divisions of the corporation. All groups affecting reliability such as Engineering, Quality Control, Purchasing, Standards and Manufacturing are represented and participate in directing the reliability program.[12]

The reliability program employed at RCA has been the subject of many other papers and those interested will find some of them referenced at the end of this one.[1,2,6,7,8]

Value Engineering Program

The value engineering program like the reliability program depends upon design review and information feedback loops. Value engineering, operating as a specific effort for little over a year at RCA, is a studied and systematic approach to cost reduction.

The approach taken by RCA is vital to the electronic industry. Second looks and redesigns cost money, take

time and are psychological barriers to an engineer's effective thinking. We have in our design review program united value engineers, maintenance personnel, operators and reliability experts as well as design specialists. At the design review's, we give the designer all the pitfalls he should avoid before he starts his design. Then, after his sketches and/or models are finished, his design is reviewed to evaluate his design in relation to the function required. After the third review, accomplished after complete prototype tests, the drawings are released for the first time. In other words, the design review program helps the engineer avoid costly engineering changes and field modification kits.

Figure 1 shows in outline form the steps taken in the value improvement program.

Our guides as to how it's done are illustrated in Fig. 2 and in Fig. 3.

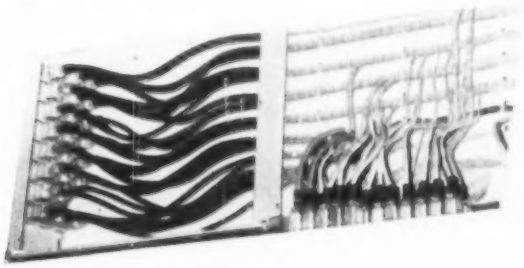

Figure 6

The entire program is integrated by a value engineering council made up of all working department representatives including Purchasing, Quality Control, Manufacturing, and Engineering. Each working department has organized a team which includes responsible, decision-making personnel from those activities having cognizance over major cost elements.

Engineering Organization

An organization chart showing the major functional groups of an engineering section is shown in Fig. 4.

Reliability can be improved by value engineering analyses when the analyses bring to light situations which are not to the best interest of the customer. Some of these situations may be:

a. Over designed structures
b. Under designed structures
c. Highly stressed components, heat, load, pressures
d. Non-essential refinements
e. Extra functions duplicated elsewhere
f. Drawing inconsistencies

Compatibility

In order to show that these two management techniques are compatible, it is felt that some specific examples would be helpful.

Example 1: "Over Flexible"

The initial design on a large, ground radar system permitted a high degree of flexibility in the placement of the physical components of the system. Cable ducts were used throughout the design and interconnecting cables were used between the sections. The length of these cables could vary depending on the need. However, the production units of this system were subsequently decided to be for similar placement of components in each system. Each production unit was to have a building built to specifications for housing the system where this was not expected in the R&D design. Since flexibility was not needed, why were these cables required? Couldn't we use one less set of connectors and perform the same task?

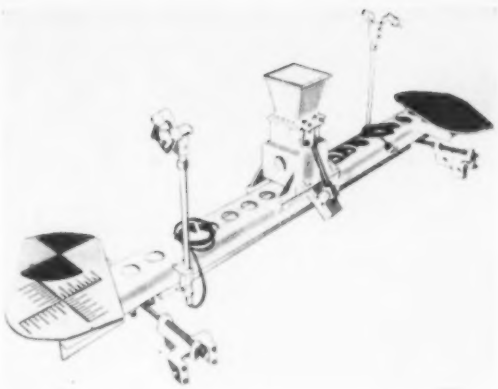

Figure 7

The "before" and "after" configurations of these cables and connectors are shown in Figs. 5 and 6.

The cost aspects of this example show that the total per unit savings amounted to $5359. However, the costs to make the change were pro-rated over the production quantity and the net savings amounted to $5030 per unit.

The reliability aspects are such that two soldering operations per wire and two connectors (male and female) were eliminated. The possibilities of human error in soldering and wiring and the unreliability that the connectors contributed to the circuit were eliminated. As noted in the figures there are many multiple connectors so involved. Actually there were 24 pairs or sets of connectors eliminated in each of four banks of connectors per system. Here is an example of *value analysis* contributing a major cost reduction and a substantial improvement in the reliability of the circuit.

Example 2: Is There Another Method?

A large ground-based Instrumentation Tracking Radar System going into quantity production by RCA's Missile and Surface Radar Department employs a boresight target for calibration purposes.

The mechanical engineer and the manufacturing methods members of the value analysis team reviewed the engineering model boresight target assembly with the express purpose of reducing its cost. The current cost of procurement is $3672 per assembly. As noted in Fig. 7, the original design contained many castings specially fabricated, a rectangular box beam and complex leveling mechanisms. The team members asked themselves—"Are there standard parts that will do the job?" The answer of course was "Yes," and the complex truss work shown in Fig. 7 was changed to a round aluminum pipe of a standard size and all clamps, levels and threaded castings were changed to standard commercial hardware, as seen in Fig. 8.

The cost was reduced by $1412 per assembly. The reliability of the assembly was altered only in that accessibility for adjustment of the targets is more rapid. We also know that assembly quality is much higher, the availability of replacement parts is no

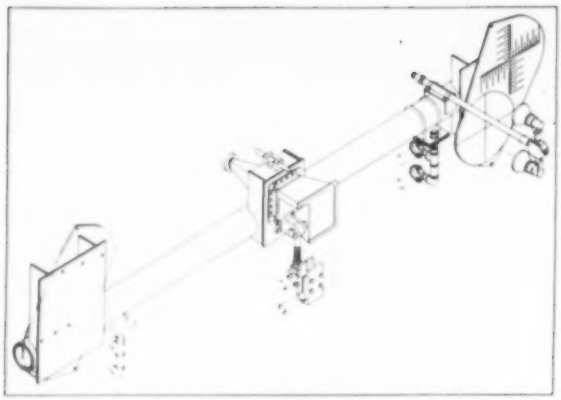

Figure 8—New Model of Boresight Target Assembly

longer a major concern of our logistics group, and installation procedure is less cumbersome and therefore more rapid.

Example 3: Are the Specifications Realistic?

In some instances a value improvement analysis results in a second look at the original specifications. It may be required that to save a considerable amount of money all that is needed is another interpretation of the customer's specification. This is due to the definitions of words or phrases used in a legal document. In one particular case the specification stated "that there shall be no flicker." If we chose to say "there shall be no flicker at any time," the cost was estimated at $12,000 for an indicator and particular power supplies. However, if we chose to say there shall be no flicker 99.5 percent of the time, the cost of the indicator and its power supply would be about $7000. The function would not be impaired by a flicker only 0.5 percent of the operating time and the customer readily agreed to the modified interpretation when he saw the possible cost reduction.

Example 4: Guide Lines

An analysis was undertaken to determine the ratio of vacuum tube cost to total material cost for electronic systems. Three basically different types of circuits were studied, and the costs per tube varied widely among the three groups. Costs per tube decreased for each circuit studied as the number of tubes increased; but more important, the analyses showed that regardless of system, when the number of tubes was fifteen or more, the costs per tube approached the same level. (See Fig. 9.) This technique promotes reliability as well as cost reduction by reducing the number of inter-chassis connectors, cabling, special heat dissipating ducts and blowers to remove heat from the large masses of metal; reduces the number of solder joints and allows more point-to-point wiring reducing the human error factor; makes circuit tracing easier; allows for more rigid construction of the chassis to withstand vibration and shock environments. The equipment may also be reduced in total weight using this technique. This cost-saving packaging method does not rule out the use of modularization, printed circuitry, or other automatic manufacturing processes. These are still available, but the fewer connectors needed, the better the reliability of the equipment.

Example 5: A Planned Program

A complete system underwent a value improvement analysis. A program was set up with the knowledge of the basic manufacturing cost accurately based on five years of prior production on the unit. A cost reduction goal was established by marketing considerations at 20 percent.

The program, through the efforts of the team members, actually reduced costs 19.8 percent. The estimated cost of the analysis was $20,500 (estimated because some team members were not direct labor and the best estimates of the time used by these members are from their own estimates of time). Even though $20,500 sounds high, each dollar spent in the program reduced the cost of the equipment by $11.40.

Due to changes in the state-of-the-art, the customer authorized a design evaluation of the equipment, so that the new unit would be more reliable, and thus more valuable to the services.

During the analysis many components were eliminated or simplified. Examples of the parts eliminated include thermistors, diodes, spacers and sleeving. Substitutions included relays, transformers and toggle switches.

These programs to improve the reliability and value-analyze the equipment are not confined to one group at RCA; it is a corporate venture. The two examples of the compatibility of VE and reliability shown below are an indication of what the other groups are doing in these areas:

a. The section is producing a system consisting of 15 racks or cabinets for the military. The design engineer in the R&D stage devised his wiring for ground and RF shielding through silver-plated beryllium copper spring-finger stock. Later, in the production design, ground wiring was adopted but the spring fingers were not removed. They were retained to provide RF shielding for the cabinet. One of the mechanical engineers seeking to reduce the cost of manufacture asked why the strips were needed. He wasn't convinced that there was a need for these strips to provide RF shielding. He then obtained two completed cabinets and removed the shielding strips from one, and had RF emission tests conducted on both. There was no measurable difference in the RF emission between the units. His

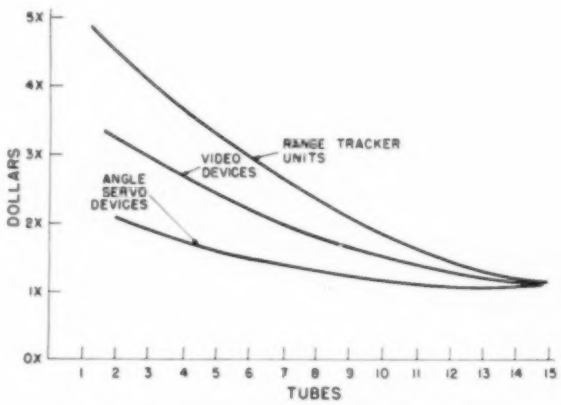

Figure 9—Standard Material Cost vs Number of Tubes (cost data coded)

curiosity and persistence brought about a saving of $122.00 per system. Engineering changes to drawings etc., cost $100.00. Therefore, on the total production run a saving of over $12,100 was made possible.

This value analysis not only reduced costs, but reduced the maintenance required on this system. Because of their location, frequent breakage of the spring-fingers occurred and they required repair in the field, since the service man was not aware that the loss of even all fingers would not be harmful.

b. There are in this large ground equipment 16 identical electro-mechanical parts which are quite complex in nature. We were in the market for some 1700 of these parts. Suitable bids were received from competent vendors. The lowest price submitted was $60.00 each.

The engineers felt that this price, although properly submitted by the vendor, was rather high for the function to be performed by the unit. Serious consideration was being given to designing this component out of the system. One engineer was sent to see the vendors that bid, to see if their manufacturing methods and/or design could be altered without affecting the function or reliability of the part. After discussing the general problem with those vendors, new bids were requested. The results showed that value improvement and value engineering can be contagious because the low vendor's final price was $25 under his original quotation, with no detectable difference in performance or reliability or overall configuration. The cost of the trips and the securing of new bids approximated $300.00. The total savings to the taxpayer on this one item alone will be in excess of $42,000.

Summary

Let us stress that last phrase: *"Savings to the Taxpayer."* Every value engineer-item cited in this article has been realized on either a cost plus fixed fee contract or on a fixed price redeterminable downward contract.

As such, these savings do not accrue to RCA but directly to the taxpayer in the form of lowered procurement costs for the equipment order by the military.

Reliability was not adversely affected but rather enhanced. Delivery, availability and maintenance problems were not altered to the detriment of the purchasing activity.

It is hoped that the foregoing examples have demonstrated that value engineering analysis goals are compatible with the military requirements of increased reliability for the service's equipment.

It should be noted that all value engineering analyses do not result in a cost reduction or a reliability improvement. The purpose of this article has been to indicate that value engineering and reliability are not in conflict with each other as has been generally supposed.

The value of reliability is a most important item, and is the primary characteristic that is considered in RCA's value improvement program.

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Control Charts Without Calculations

Some Modifications and Some Extensions

PAUL C. CLIFFORD

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Abstract

The usual control chart for variables requires a separate data sheet, a reasonable amount of arithmetic, and two charts. The computation of control limits frequently requires the elimination of some of the original data. And for shop personnel there is still confusion between control limits and specification limits. A method is presented in which individual measurements are plotted, thus eliminating the data sheet. Control limits are established by a process of measuring and counting. Such charts lend themselves to a variety of applications, some of which are considered. In particular this procedure gives a simple comparison of process capability and process achievement.

The Industrial Efficiency of Control Procedures

Control charts using the range have almost completely replaced charts using the standard deviation. One reason is simplicity of computation. A second is that the range is a better indicator of certain sorts of trouble. Considering the industrial usefulness of the range, it is surprising that substitute measures for the average-range chart have received so little consideration. Ferrell in an excellent paper[1] has presented the advantages of the mid-range. Much of the theory in Ferrell's article is pertinent to the charts presented in this article. The Narrow-Limit gaging procedure of Ott and Mundel[2] and the Pre-Control procedures developed by Shainin and Satterthwaite[3] are examples of plans that are based on the characteristic of an individual item rather than on some statistic computed from these individuals.

There is a wide variety of control problems for which the quality control engineer needs an extensive kit of techniques. Operationally the problems run from first piece inspection and equipment set-up inspection to multiple factor experiments designed to discover well concealed causes of trouble. Statistically we have a battery of tools ranging from distribution analysis and control charts to regression analysis, analysis of variance, surface response estimation and so forth. In evaluating any industrial procedure I would suggest that there are at least four aspects: *engineering, economic, statistical, psychological.* Just because the statistical aspect is the easiest to evaluate, we tend to overvalue the statistical efficiency and lose sight of the other aspects.

Thus the charts presented here have advantages, but in general they are not based on arguments regarding statistical efficiency. Rather this is a report on several years industrial experience which has confirmed my intuitive belief that such charts have a wide area of application. In general this area is definable as "Problems or processes that require more than first piece inspection and less than three factor designed experiments." I do not propose that these should replace $\bar{X} - R$ charts. My belief is that there is no universally best chart—the proper one will depend on the process, the personnel, and the type of instrumentation and the importance of the problem.

Control Charts Using Individuals in Sub-Groups

To facilitate comparison with the usual chart I have taken an example from Grant[4] page 18. I shall not reproduce the data, for in the proposed procedure, no record form is used. Rather the readings in each subgroup are plotted directly, the five points being plotted along a vertical line segment as shown in Fig. 1. For this one should use rather coarse graph paper with large squares, since for most characteristics 10 to 30 units of measurement cover the range of variation encountered. We now proceed to change this plot of individuals to a control chart.

The first step is to indicate the median of each sample, which we have done here with a circle. Next, using a reference card, the individual ranges are *measured.* To do this the bottom edge of the card is placed at the lowest reading of the subgroup, and a mark is recorded opposite the largest reading in the same sub-group. Having marked the 20 ranges on the card (shown on the right of Fig. 1), we count down to the middle mark.

This gives us the *median range*. While it is sometimes necessary to interpolate, it is usually better to be conservative, so we take the median range as 5. We next look up the factors for the control limits on the range. These are given in the appendix as $\widetilde{D}_3$ and $\widetilde{D}_4$. In this case $\widetilde{D}_4$ equals 2.179. This gives a range control limit of 10.5. The index card shows that three ranges are outside this limit. We make a range control rod as shown on the right, with the median range and the maximum range indicated. We then locate these three sub-groups that are out of control and circle them as shown on the chart.

Next we draw in a *center line* on the chart. Here we may use either the *median of the sub-group medians* or the *median of the individual observations*. The number of subgroups is the deciding criteria. With only 20 sub-groups it is better to take the median of the individual observations which in this example is 33.5. We then look up the $\widetilde{A}_2$ factor for medians which for $n = 5$ is 0.712. This factor multiplied by the median range gives a product of approximately 3.5. Control limits are drawn at this distance on both sides of the center line. Sub-groups 12 and 18 have medians that are outside these control limits.

In a process that is so badly out of control there is not much use in adding limits for individuals. This has been done here just to illustrate the procedure. Dividing the median range by the $\widetilde{d}_2$ factor for $n = 5$ gives an estimate of sigma for individuals of 2.2. Multiplying this result by 3 gives a product of 6.6. Control limits for individuals can be drawn at this distance on either side of the central line. These control limits are 27 and 40. These are our estimates of process capability *provided a state of control can be maintained.*

At this point it might be pointed out that the usual analysis as given in Grant arrives at essentially the same result. However, to do this requires two or three recomputations as out of control results are discarded. Such procedures tend to make the novice feel that if he keeps at it long enough he will discard all the data.

We may wish to have an overall measure of what the process actually produced. We could of course make a frequency distribution of individuals and find the mean and standard deviation of this distribution. However, such accuracy is seldom needed. We already have 33.5 as a measure of center. What is needed is a measure of variability which *includes* the *five* samples that showed out of control conditions. To obtain this simply we count in 7 observations from each end. This gives us the 7 and the 93 percentile points. In this example these are 28 and 38.5 respectively. Taking one third of this difference (the correct multiplying factor is 0.3388) gives an overall standard deviation of 3.5 as a measure of *process achievement*. If we compare this overall standard deviation to the estimate of the within group variability (3.5/ 2.2) we find that the variation in the process is approximately 60 percent more than we would have if the process could be controlled.

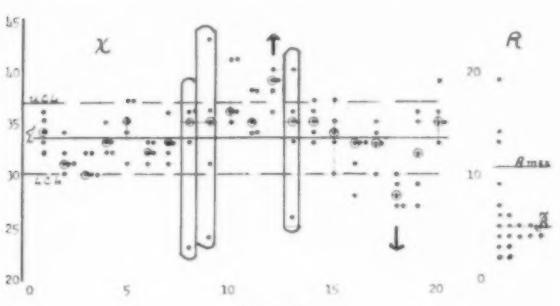

Figure 1

Finally, it seems to me that control charts should be summarized before we become embarrassed by ancient history. Let us assume that the above data represents some unit—production, time or merely the end of a graph sheet. It can be summarized as follows:

Average	33.5
Process Capability	± 6.6
Process Achievement	±10.5
$\widetilde{X}$ out of control	2
R out of control	3

Evaluation and Criticism of the Median Sub-Group Chart

The chart has several definite advantages that might be listed:

1. The data sheet and the arithmetic involved in finding $\bar{X}$ and $\bar{R}$ have been eliminated.
2. Since both the X median and the R median are not greatly affected by out of control data, recomputation of the center lines and control limits is practically never necessary.
3. The center line on the chart is the proper one for runs above and below the median.
4. Since individual results are plotted, it is possible to show both control limits and specification limits.
5. Comparisons between process capability and process achievement are easy to make. The chart can easily be summarized.

Any chart has disadvantages—at least in the wrong application. If the individual observations on the data sheet have auxiliary information tied to them—such as the piece part number, machine position or material—we may find that a data sheet is necessary If the data sheet is necessary, I see no reason for using this type of chart. It is obvious that the chart emphasizes the average and soft pedals the range, and that it is most useful in those applications where the control of the average is of major importance.

The Mid-Range Sub-Group Control Chart

A rather obvious adaptation is the chart where Mid-Ranges are used as the measure of center. In this case we plot only the extreme readings and the average of the extremes. The analysis of ranges is the same as we have outlined above. The control limits for Mid-Ranges require a slightly different factor which I have indicated by $\widetilde{A}_2$. This chart has many of the advantages listed above. It does not have advantage number 5. I find that the decision between the median chart and the mid-range chart depends to a great extent on the process. There are some generalizations that help in this decision:

1. From the viewpoint of statistical efficiency for sampling from a normal distribution, the midrange is as good or better than the median or sub-groups of $n = 3, 4, 5$. For n greater than 6 the median is more efficient.
2. The statistical efficiency of mean, median and midrange all depend on the type of distribution. The mean is most efficient for the normal distribution. For distributions with limited range the efficiency

of the mid-range increases.[5] For distributions with extremely long tails such as the Tukey distribution[6] the median is the more efficient.

However, sampling from a fixed population is only part of the story. If we have lack of control we have an indication that there is no one population involved. In such a case the median range is superior to the average range, since the 'contaminated' ranges have less effect on the median. If the percent of contaminated ranges is very high, say 20 or 30 percent, this procedure will be poor, but so will any procedure.

This question of contamination is important in choosing between the two charts. Suppose one sub-group had four typical readings and one unusually high reading. This high one we shall suppose is a 'wild shot.' Do we want our measure of center to show as outside our control limits? I think the answer is that in production we would not, while in research and development we would. I believe that this may be the reason why Ferrell prefers the mid-range chart and I prefer the median chart —we are expressing our differences as to what we want the chart to show in different types of applications. On a sample like the one described I am afraid that the operator will reset the process—Ferrell is afraid that the engineer will ignore possible troubles.

We have admitted that if the process is in control either the mid-range or the median is likely to be less efficient than the average. However, I question whether this is a real deficiency and might even claim that it is an advantage. I find that the usual trouble with control limits is that economically they are too 'tight' and that as a result there is difficulty in getting people to take any action when the charts show points out of control. It may be that wider control limits would be a real benefit. As an example consider a process with specification limits of $\pm 4\sigma$.

Control limits for the average would be	$\pm$ 1.34σ
Control limits for the median would be	$\pm$ 1.61σ
Modified limits for the average would be	$\pm$ 2.34σ

It appears that the less sensitive limits for the median would not be a disadvantage unless maximum control is needed.

Control Charts for Sub-Groups, Two Way Classification

In many applications each observation may be classified in two ways. One is usually time, the second is frequently position. As an example Fig. 2 shows the results of Preece Dip Test on the amount of galvanization on wire. In this case a galvanizing bath carried thirty wires. For sampling purposes the bath was considered as being in five sections, and one wire was selected from each section. The wire numbers of the highest and lowest

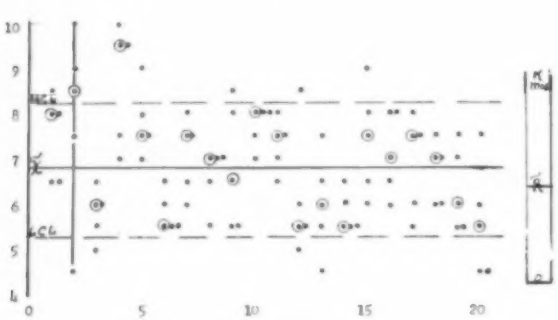

Figure 2

readings were recorded on the chart, but have not been shown here. Samples 2 and 4 are out of control on the median. The cause turned out to be the method of charging plus a defective electronic control. Sample number 2 is also out of control on the range. Both the high and the low readings were investigated. It was discovered that the same wire was sampled on samples 2, 12, 13, and 16, the readings being 4.5, 5.0, 4.5 and 6. It appears that this wire is giving unusually low readings. The cause appeared to be a defective die.

This example is given to indicate the type of application. I have found this most useful in analysis of multiple spindle machines, filling operations with multiple heads, batch sampling with stratification and so forth.

Control Charts for Skewed Distributions

The distribution of the median is approximately normal for moderately skewed distributions. For very skewed the data is sometimes transformed by taking logarithms. This same result can be accomplished graphically by plotting the individual readings on semi-logarithmic paper. Figure 3 shows an example taken from Cowden.[9] The individual items are plotted, the median of each sub-group is circled, and the range of each group is *measured* using a reference card as before. The Median range is then found by counting. In this example the median range is just less than the length of one cycle on the log scale. This *distance* is then multiplied

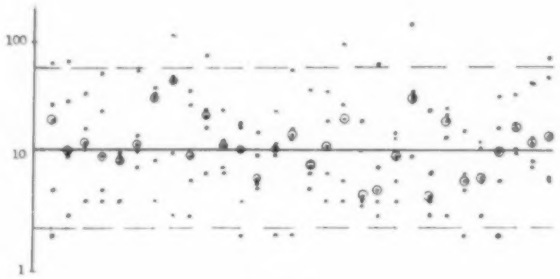

Figure 3

by the factors $D_4 = 2.179$ and $A_2 = 0.712$. The ranges in this example are all in control. The distance to the control limits for medians is *measured* off on each side of the center line. In the example the center line is 11.5 and the control limits are 2.3 and 58. All the medians are inside these control limits. Three sigma limits for individuals can be found by taking the median range (distance), dividing by $d_2 = 2.257$ and multiplying by 3. This distance when laid off from the center line gives three sigma limits for individuals of 0.5 and 250.

The usual control chart for average and range shows several points out of control as can be seen in Cowden. Cowden handles this problem by finding the log of each observation, and making a control chart for this transformed data. This involves looking up the logs of 150 numbers plus the arithmetic to make a control chart. The time by the proposed method is that required to plot the readings, plus three minutes to find the limits. The results are practically identical.

Control Charts for Individual Observations

In some applications, especially in the process industries, there is no rational way for sub-grouping the data. In other applications it may be that a sample of more than one is not justified economically. Figure 4 shows individual test results on a natural product used in the

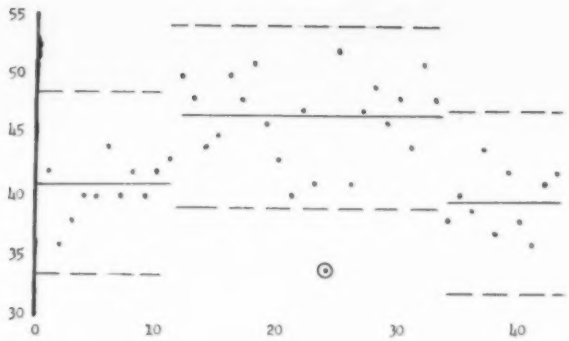

Figure 4

chemical industry. The ranges are found by measuring from one reading to the next. The median range is 3.5. Since individuals are so insensitive to shifts in average we used two-sigma control limits. These are obtained by dividing the median range by $\tilde{d}_2$ of 0.954 and multiplying by 2. This gives control limits of $\pm$ 7.5. The median of the X's is 42.5 and we can easily see that there are many points out of control. Examination of the chart shows evidence of either a cycle or a shift in average. In this case a cycle would have no operational meaning, but a shift in average could be readily explained.

To analyze the data for shift, a center line and control limits were drawn on clear plastic. This plastic overlay is then shifted up and down vertically. The number of runs above and below the median must be watched carefully. After several trials we find that there appear to be three different levels or batches, as is indicated on the chart. We cannot guarantee that the batches terminate where the chart indicates they do. However if we can adjust the process to compensate for difference in batches, we have the approximate place to make the change. One test result on sample number 24 is a "wild shot" and should be investigated or the material set aside.

The use of any gadget, such as the plastic overlay is difficult to describe and easy to demonstrate. There is of course the criticism that one does not have exact probability levels for such an eye test. The same is true of any similar procedure, such as fitting a line to cumulative data on probability paper. Moreover I know of no exact statistical method for segregating batches such as we have attempted here. I can state that the actual industrial application was successful, but I cannot deny that I may have been fortunate. However the same procedure is very useful when we know that there are definite batches.

Multiple Control Charts on Individual Observations

Control charts on individual observations are especially useful when several different characteristics are recorded for each sample. Since the characteristics can be plotted one below the other, it is easy to keep records on four or five characteristics on one sheet of graph paper. I know one industry where five process charac-

List of Short Courses in Quality Control

Usual Time Course is Held	*Type of Course*	*Where Held*	*Course Director*
February	Basic	University of Illinois, Urbana, Ill.	J. A. Henry
February	Basic	Michigan State, Lansing, Mich.	W. D. Baten
June 8-19, 1959	Basic	Marquette University, Milwaukee, Wis.	Gayle McElrath
June	Advanced	Purdue University, Lafayette, Ind.	I. W. Burr
June	Basic (Chem. Ind.)	Rochester Institute of Technology, Rochester, N. Y.	R. D. Pease
June 29-July 10, 1959	Op. Research	University of Michigan, Ann Arbor, Mich.	Oscar Wesler
July 20-31, 1959	Basic	TAPPI Statistics Conference	M. S. Renner
July 20-31, 1959	Advanced	TAPPI Statistics Conference	M. S. Renner
July	Advanced	University of Oklahoma, Norman, Okla.	R. L. Huntington
August 10, 1959	Basic (Research)	North Carolina State College, Raleigh, N. C.	....
August 10, 1959	Advanced (Research)	North Carolina State College, Raleigh, N. C.	....
August	Basic	University of Michigan, Ann Arbor, Mich.	C. C. Craig
August 3-14, 1959	Basic	U.C.L.A., Los Angeles, Calif.	Edward Coleman
August 3-14, 1959	Advanced	U.C.L.A., Los Angeles, Calif.	Edward Coleman
Aug.-Sept.	Basic	University of Connecticut, Storrs, Conn.	R. M. Story
September	Basic	Washington University, St. Louis, Mo.	D. J. Kaufman
September	Advanced	Rutgers University, New Brunswick, N. J.	M. E. Wescott, E. R. Ott
September	Basic	University of Mississippi, Oxford, Miss.	Gayle McElrath
October	Basic	State University of Iowa, Iowa City, Iowa	L. A. Knowler
October	Basic (Graphic Arts)	Rochester Institute of Technology, Rochester, N. Y.	R. D. Pease

teristics and two final product characteristics are analyzed in this fashion. It is possible to observe not only the effect of changes in individual characteristics on final quality, but also the interaction in changes of two or more characteristics. Space does not permit discussion of such charts, but it would appear that the application is obvious.

Control Without Charts

The question as to when a chart has outlived its usefulness is a difficult one to discuss. However the usual statement that removal of charts is dangerous just does not square with the facts of industry. By this time industry has discarded more charts than they have retained. I suggest that we should take a good honest look at the problem, and I believe that there are many cases where a chart is not needed. My question is—*How much control?* The control chart for medians can be easily adapted to a procedure without charts. To do so requires that the process capability has been determined and is less than the specifications. To be specific let us refer to Fig. 1. Let us assume that the process is near a state of control, that the target of 33.5 is satisfactory, and that control is to be based on a standard deviation of 2.5. The operator is given the following instructions:

1. Measure each of a sample of five items
2. The median is to be between 33.5 ± 4.0 ($\widetilde{X} \pm \widetilde{A}\sigma$)
3. The range is to be less than 13
4. If the results are out of control in one out of 20 checks the process is satisfactory. If out of control more than one time in twenty, a chart will be temporarily reinstituted.

This procedure can be easily adapted to most measuring instruments by using a slightly frosted plastic overlay. On this the operator marks each reading as he takes it. The control limits for the median are premarked on the overlay. If it is necessary a parallel scale giving the limits for the range could be attached. I have never found this particularly useful.

Summary

Industrial experience has indicated that there are many cases where a similar procedure than the usual control chart would be useful. Some of the advantages of control charts using individual observations, with control based on the median, have been indicated. Some applications to different types of control problems have been indicated. These charts have been used in a variety of industries and the economic and psychological advantages appear to outweigh any statistical disadvantages in many applications.

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(8) Dixon and Massey, *Introduction to Statistical Analysis*, McGraw-Hill, New York (1957)

Mathematical Appendix

Unfortunately there is no standard set of symbols for medians and midranges. The symbols used here have one advantage—the formulae for median and midrange charts are similar to the standard one for **X** and **R** charts. The symbols are defined as follows:

$\widetilde{X}'$ = median of parent universe

$\widetilde{X}$ = median of sub-group

$\overline{X}$ = midrange of sub-group

$\widetilde{X}_i$ = median of all individuals in sample

$\widetilde{X}$ = median of sub-group medians

$\widetilde{\overline{X}}$ = median of sub-group midranges

$\widetilde{R}$ = median of sub-group ranges

Standards Given $\quad \widetilde{d}_2\ \sigma' = \widetilde{R}'$

$\widetilde{A}_2\ \widetilde{R}' = 3\ \sigma_{\widetilde{x}},\ \overline{\widetilde{A}}_2\ \widetilde{R}' = 3\ \sigma_{\overline{\widetilde{x}}},\ \widetilde{\overline{A}} = A\ /\ \sqrt{E_{\widetilde{x}}}$

$\widetilde{D}_3\ \widetilde{R} = D_3\ R,\ \widetilde{D}_4\ \widetilde{R} = D_4\ R,\ \widetilde{\overline{A}} = A\ /\ \sqrt{E_{\widetilde{x}}}$

Estimates: $\quad \widetilde{X}' = \overline{X}$ or $\widetilde{X}_i$ or $\widetilde{\overline{X}}$

$\sigma = \widetilde{R}\ /\ \widetilde{d}_2$

3 σ Limits for $\quad \widetilde{X} \quad X \pm \widetilde{A}_2\ \widetilde{R}$ or $\widetilde{X}_i \pm \widetilde{A}_2\ \widetilde{R}$

$\overline{X} \quad \widetilde{\overline{X}} \pm \overline{\widetilde{A}}_2\ \widetilde{R}$

$R \quad \widetilde{D}_3\ \widetilde{R}$ and $\widetilde{D}_4\ \widetilde{R}$

Note: $E_{\widetilde{x}} = \sigma_x^{\ 2}\ /\ \sigma_{\widetilde{x}}^{\ 2}$. This is tabulated in reference 8. The tables that follow have been computed from references 1, 6, 7 and 8.

Factors for Median and Midrange Charts Using Median Range Normal Distribution Theory

n	$\widetilde{A}$	$\widetilde{\overline{A}}$	$\widetilde{A}_2$	$\overline{\widetilde{A}}_2$	$\widetilde{d}_2$	$\widetilde{D}_3$	$\widetilde{D}_4$
2	2.121	2.121	2.224	2.224	0.954	0	3.865
3	2.014	1.806	1.265	1.137	1.588	0	2.745
4	1.637	1.637	0.829	0.829	1.978	0	2.375
5	1.615	1.532	0.712	0.679	2.257	0	2.179
6	1.387	1.458	0.562	0.590	2.472	0	2.055
7	1.385	1.402	0.520	0.530	2.645	0.078	1.967
8	1.233	1.358	0.441	0.486	2.791	0.139	1.901
9	1.240	1.322	0.419	0.453	2.916	0.187	1.850
10	1.216	1.293	0.369	0.427	3.024	0.227	1.809

A Variables Sampling Plan for acceptance of punched mica holes

LEWIS GARLICK, JR.

Westinghouse Electric Corporation, Bath, N. Y.

Introduction

Described in this article is an example of a variables sampling plan which resulted in lower inspection costs and better quality assurance.

Problem

One problem confronting manufacturers of receiving tubes is inspection of holes punched in the pieces of mica which are used to position the tube elements. Of particular importance is the fit of the mica holes to the cathode and grids of the tube. These elements are usually round. However, a "round" mica hole as punched is not truly round because of shattering of the mica around the hole. The resulting hole is irregular in shape as is shown in Fig. 1. The measurement made is the minimum cross-sectional diameter of this irregularly shaped hole. The method of measuring these holes is fairly slow so that it is impractical to use a sampling plan as large as is called for in the MIL-STD-105A attribute sampling tables.

A favorite inspection plan used in the receiving tube industry for punched mica holes is a sequential sampling plan having an AQL of 10 percent and an LTPD of 25 percent. Part of this plan is shown in Table I.

Use of this plan was not very satisfactory because the work load was unpredictable and a lower AQL was desired.

For a three month period of time, readings of hole size were recorded for ten micas out of each shipment received for several different types of mica. It was found that the distribution of hole size had a standard deviation of 0.000193 inches and that the standard deviation stayed in control over this period of time. What was found to vary was the center of the distribution.

TABLE I

$P_1 = 0.10$ $P_2 = 0.25$ $\alpha = 0.05$ $\beta = 0.10$

NO. INSPECTED	ACCEPTANCE NO.	REJECT NO.
	d_1	d_2
4	—	4
13	0	4
14	0	5
18	1	5
20	1	6
24	2	6
26	2	7
30	3	7

It was decided to develop a variables sampling plan using:

1. $\sigma' = 0.000193$ inches
2. AQL = 6% with risk of $\alpha = 0.05$
3. Sample size, $n = 10$
4. Acceptance to be based on comparison of sample average $\bar{X}$ with predetermined acceptance limits.

Used, in general, are three standard tolerances for mica hole size, ± 0.001, $^{+0.001}_{-0.0005}$ and ± 0.0005 inches. Obviously, the first two are well in excess of the 6 σ_x' of 0.001158 inches. The third specification of ± 0.0005 inches, or a total spread of 0.001 inches, is slightly less than the process capability so that there is a very small percentage of defective product both above and below specification limits when the product center is at the specification bogie.

However, in devising the inspection plan, the aim was at giving protection against lots either having too high a proportion of mica holes below the minimum limit or having too high a proportion of mica holes above the maximum limit. Protection against lots which may have simultaneously too high a proportion of mica holes out-

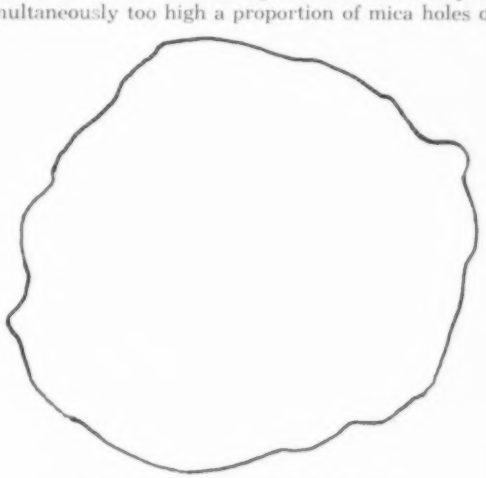

Figure 1—Outline of Punched Mica Hole

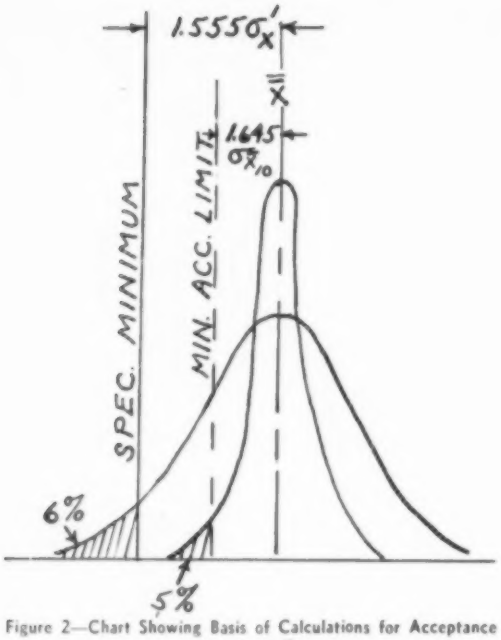

Figure 2—Chart Showing Basis of Calculations for Acceptance Limit of X

side both minimum and maximum specification limits was not sought because it is the moving of the product center toward either of the specification limits, so that a high proportion of the product is either too large or too small, which bothers the operational characteristics of the manufactured product. Therefore, one sided risks were used in the calculation of the operating characteristics of the sampling plan.

The method for calculating the acceptance limits for sample averages is as follows. (See Fig. 2 to visualize the situation at the low side of specs.)

$$\sigma_{\bar{X}_{10}} = \frac{\sigma_X}{\sqrt{n}} = \frac{0.000193}{\sqrt{10}} = 0.000061 \text{ inches}$$

Normal deviate t for AQL of 6% = 1.555

Normal deviate t for 95% Lot acceptance of AQL Lot = 1.645

$$\begin{aligned}\text{Min. Acc. Limit} &= \text{Spec. Min.} + 1.555\,\sigma_{X'} - 1.645\,\sigma_{\bar{X}_{10}} \\ &= \text{Spec. Min.} + (1.555)\,(0.000193) \\ &\quad - (1.645)\,(0.000061) \\ &= \text{Spec. Min.} + 0.0003 - 0.0001 \\ &= \text{Spec. Min.} + 0.0002\end{aligned}$$

$$\begin{aligned}\text{Max. Acc. Limit} &= \text{Spec. Max.} - 1.555\,\sigma_{X'} + 1.645\,\sigma_{\bar{X}_{10}} \\ &= \text{Spec. Max.} - 0.0003 + 0.0001 \\ &= \text{Spec. Max.} - 0.0002\end{aligned}$$

In other words, the average hole size for a sample of ten micas can be no closer than 0.0002 inches to the specification limits.

The LTPD for this sampling plan is calculated for a risk of $\beta = 0.10$ as follows (see Fig. 3):

Normal deviate t for 10% lot acceptance = 1.282

$$\begin{aligned}\text{Distance of } \bar{X} \text{ to limit} &= 0.0002 - (1.282)\,(0.000061) \\ &= 0.0002 - 0.000078 \\ &= 0.000122 \text{ inches}\end{aligned}$$

$$\text{Normal deviate, } \bar{X} \text{ to limit} = \frac{0.000122}{0.000193} = 0.632$$

Percent below t = 0.632, i.e., LTPD = 26.4 percent

The plan then accomplished its purpose of lower AQL and less inspection cost without seriously affecting the LTPD.

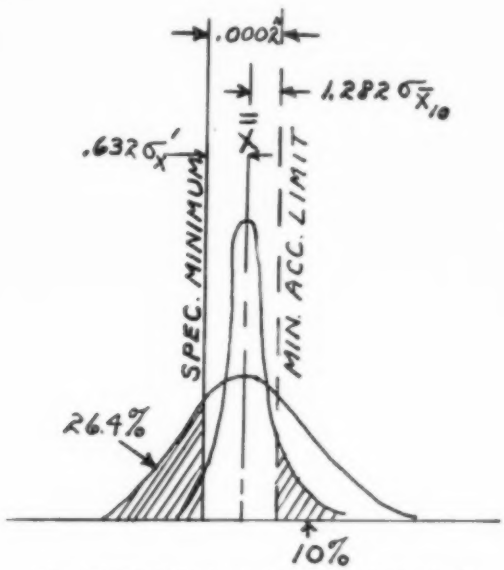

Figure 3—Chart Showing Basis of Calculation for LTPD

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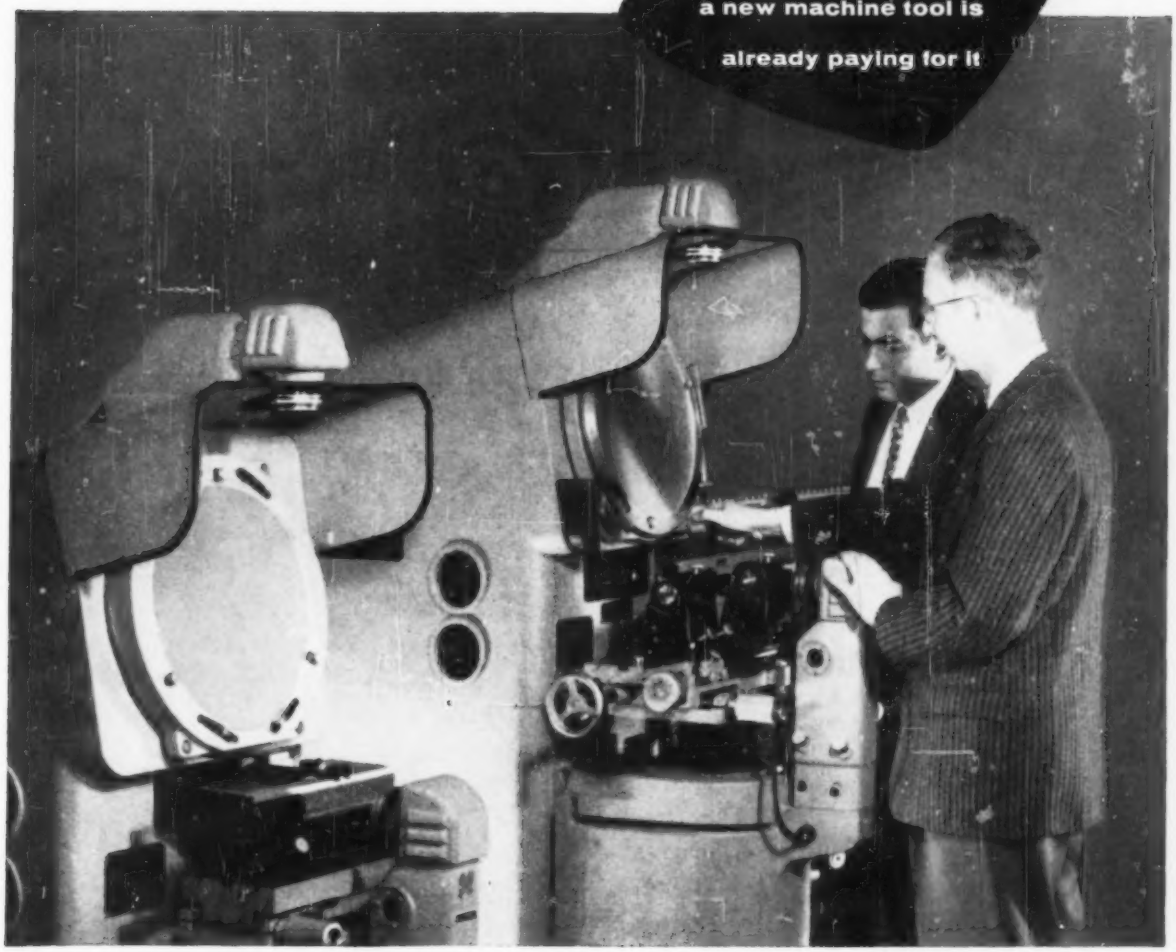

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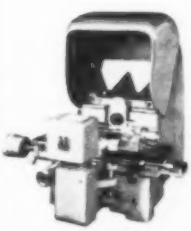

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From the Scrap Box

MASON E. WESCOTT, *Editor*

Rutgers • The State University, New Brunswick, N. J.

Some Data on the Evaluation of a Quality Control Program

ELLIS R. OTT

Rutgers • The State University, New Brunswick, N. J.

Summary

The evaluation of any product or process can be improved if a measure of its performance is possible. Our immediate interest is two-fold: (a) to list and classify the important aspects of a modern quality control program within a company, and then (b) to evaluate the performance of quality control programs in companies as rated by a special group of employees who are graduate students in Applied and Mathematical Statistics.

Perhaps you would like for some of your colleagues to rate the effectiveness of these quality functions in your own company. Thus, you might want to prepare blank Quality Control Rating forms similar to the one shown in Table I. You are welcome to do so. Then a summary of the different responses will indicate areas which should be emphasized.

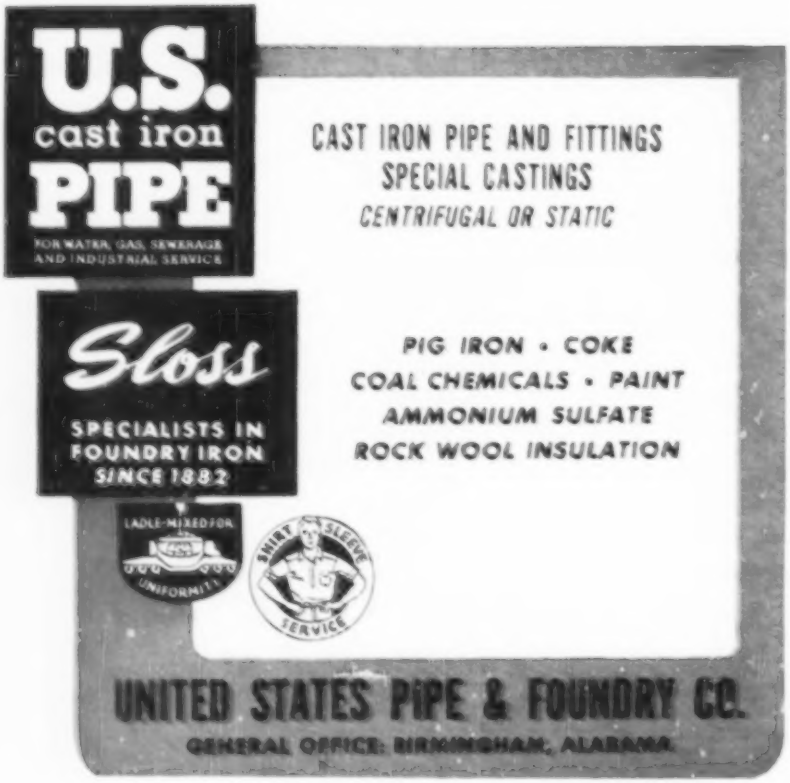
Functions

After a company has approved the manufacture of a product there are problems of design, manufacturing, testing, rework and scrap, customer acceptance, redesigning, and others of a manufacturing, engineering, cost, or accounting nature. These problems are at the core of a company's successful operations, and are the problems which must be solved by whatever methods are effective. During the last ten years, there has been a remarkable advance in applying quality control methods and approaches to these functions.

Important Functions and Ingredients of a Program of Total Quality Control

Areas of activity for a total quality control program include the following; these may or may not all be vested within a single department of a company:

1. *Design* of the product, and the setting of appropriate *specifications* on component materials, sub-assemblies, and processes.
2. *Incoming inspection* of materials, components, sub-assemblies.
3. *Routine process controls* to aid manufacturing in producing an economical and quality product.
4. A *feed-back system* of information from the various routine control and inspection stations (whether sampling or 100 percent inspection).
5. A provision throughout to assure *effective use of feed-back* information.
6. *Process improvement methods* of modern vintage including:
   (a) Routine process controls
   (b) A feed-back system both from process control stations and outgoing product analysis.
   (c) Modern methods of studying processes including fractional factorial experiments, methods of opti-



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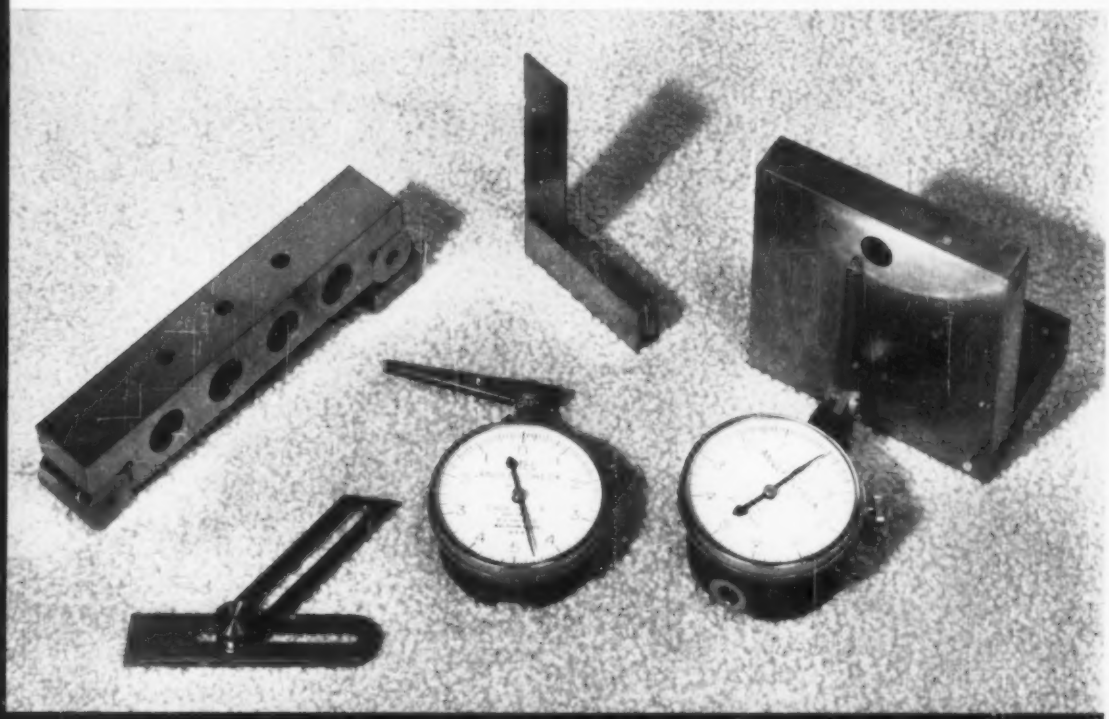

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8. A consciousness on the part of management of the contributions which practical statistical techniques can offer, economically, in designing, developing, manufacturing, and selling a product whose quality is neither better nor worse than is economically feasible in a given design.
9. A careful evaluation of samples of product awaiting shipment to the customer (quality rating; quality assurance).
10. Provision for a management structure to integrate the preceding "ingredients".

The pioneering ideas of scientists at the Bell Telephone Laboratories, notably Walter A. Shewhart and Harold F. Dodge, begun in 1924, were accepted by the United States Government as an inspection basis for the purchases of many strategically important items in World War II. As a consequence, training programs on the fundamental methodology of Shewhart Control Charts, Dodge-Romig Acceptance-Sampling Plans, and other useful methodology were organized in several different cities in the U. S. under Engineering Science Management Defense Training programs (ESMDT). Following World War II, there has been a continuing effort to train industrial personnel in the basic methodology of the new science of quality control, but inadequate attention given to the development and extension of them to become effective heads of a "total quality control" program.

It has been assumed too often, and sometimes without realization, that the teaching of statistical methods to engineers and scientists will automatically provide an implementation of the functions outlined above. This is an extreme and unrealistic position. At the other extreme, it has sometimes been proposed that these functions can be established effectively by persons proficient as managers of industrial operations but who are not themselves familiar with the statistical methodology applicable to these functions.

It is important to provide both of these functions in an integrated organization if we are to have an effective Total Quality Control program. There are few persons trained to provide both of these functions, and their implementation is usually provided by a team of at least two persons. Three references are given below for those who may be interested in a more detailed description of the quality control functions.

In order to have some objective data regarding the type of quality control programs actually in operation within some companies (most of them in North Jersey), a short quality function rating form (see Table I) was prepared. This was then given to a group of 34 industrial personnel who are intimately associated with the quality control functions within their own companies and who are simultaneously receiving quality control training in the graduate program at Rutgers University; each was asked to fill out the form rating performance regarding the above outlined functions in a total quality

TABLE I

QUALITY CONTROL RATING FORM

Directions: Please rate your own company with respect to the following aspects of a Total Quality Control program by an appropriate check (√):

QC Function	Very Good	Good	Fair	Warrants Special Effort
Routine process controls	3	16	9	3
Incoming inspection	2	15	10	2
System of feedback of information	1	9	(16)	5
Use of feedback system	2	3	(14)	(11)
Process improvement (and trouble shooting)	1	11	(14)	5
Outgoing product evaluation or quality assurance	7	12	5	4
Managements' QC consciousness	5	13	9	5
QC consciousness (others)	2	10	(12)	8
Research, development	5	6	(11)	6
Evaluation of cost of bad quality	1	3	5	(19)

Note 1: *The numbers in the spaces indicate the number of the (34) persons who rated their own companies in this way. (Not all persons rated their own companies in every one of the categories.)*

Note 2: *The circled numbers in various spaces indicate some outstanding areas needing improvement in the quality control functions; means of improvement should receive attention by ASQC and other educational and professional groups which have a vital stake in the professional advancement of Quality Control.*

Note 3: *The 34 persons participating in the study* **do not** *represent an "unbiased" group—each of them has had at least two courses in Quality Control and Applied Statistics in the graduate program at Rutgers—thus they represent "companies with some above-average trained QC employees; simultaneously, their understanding of the industrial potential of Quality Control is above average, and they understand what might be expected of a Total Quality Control program.*

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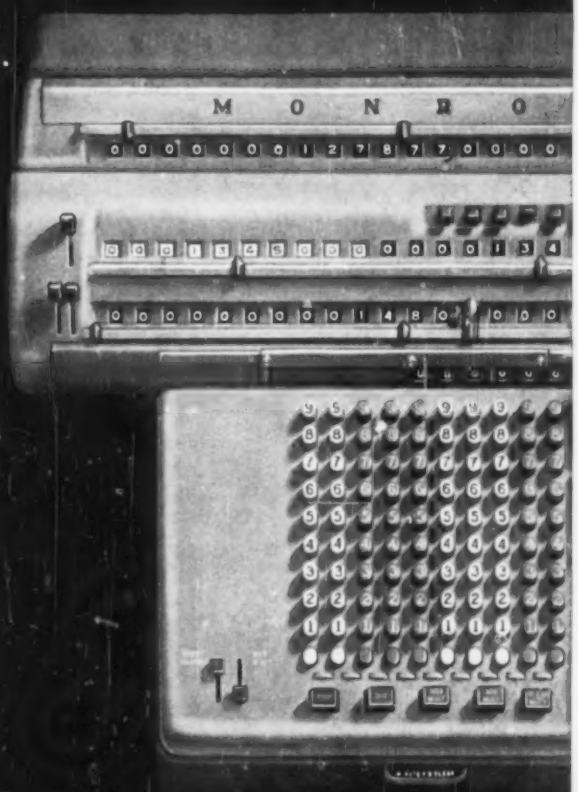

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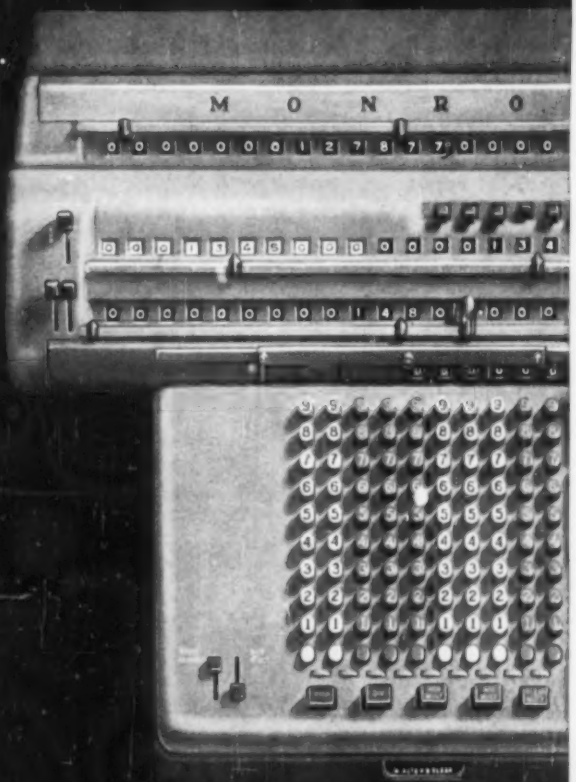

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control program. A summary of the rating form results is given in Table II.

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1. Feigenbaum, A. V., "The Challenge of Total Quality Control," *Industrial Quality Control*, Vol. XIII, No. 11, May 1957, p. 17-23
2. Ott, Ellis R., "Statistical Quality Control," *Transactions of the American Society for Mechanical Engineers, Ten Years' Progress in Management*, May 1953
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TABLE II

Summary of 34 Rating Form Replies

I. "Weighted ratings" of the following 10 important functions (or ingredients) of a Total Quality Control plant program by employees of (in the main) New Jersey industry, are given in II. The 34 employees are also graduate students in Applied and Mathematical Statistics at Rutgers and currently registered for Stat 586 (Interpretation of Data). The employees classify their company positions as (primarily):

	Number
Research and Development	14
Quality Control Engineers	12
Quality Control Chemists	3
Industrial Engineers	2
Mathematical Statistician	1
Production Supervisor	1
Test Engineer	1
	34

II. Weighted ratings of their company's Quality Control functions were obtained by assigning ratings as follows: Very good = 3; Good = 2; Fair = 1; Needs serious attention = 0. Ratings of the 10 Quality Control Functions throughout the companies represented by the 34 employees were as follows:

Quality Control Function	*Average Rating*	*Rank*
A. Outgoing product evaluation (quality assurance)	1.8	1
Routine process controls	1.61	2
Incoming inspection	1.59	3
Management's quality control consciousness	1.57	4
Research and development	1.36	5
Process improvement (trouble-shooting)	1.26	6
Feedback system of information	1.18	7
Quality Control consciousness	1.17	8
Use of Quality Control feedback system	0.87	9
Evaluating cost of poor quality	0.50	10

Note: *Some of these results were quite unexpected, at least to the author. And if indeed, for example, the "Use of the feedback system" warrants no higher rating than it received in our several companies, then major educational attention should be given to improve the situation.*

B. 4 persons rated their companies as having: 4 of these functions as Very Good.
3 persons rated their companies as having: 3 of these functions as Very Good.
2 persons rated their companies as having: 2 of these functions as Very Good.
9 persons rated their companies as having: 1 of these functions as Very Good.
16 persons rated their companies as having: 0 of these functions as Very Good.
34

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PAUL A. ROBERT, *Editor*

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Work Simplification *Applied to Inspection Part I*

ELMER N. BARRY

Introduction

"Charlie, you have *got* to reduce our inspection costs."

Recently, many Inspection Supervisors have become more than slightly familiar with these words. As industry becomes increasingly cost conscious, more and more emphasis is being placed on indirect costs such as inspection, material handling, clerical work, etc. With the advent of more highly mechanized shop operations through the use of automatic machines, conveyorized production and storage, punch card accounting and control, and other devices, managements have made phenomenal strides in reducing costs—however, the end is not yet in sight. To be successful today, yes, even to survive, we must be even more resourceful in devising new ways of producing more economically. It has been said that we are living, not in the era of a guaranteed annual wage, but in the era of a guaranteed annual wage *increase*. To provide the increase in wages, now so taken for granted not only by organized labor but by all of us, our creative talents must be mined and remined to provide the ideas which reduce costs.

Now, what have *we*, as inspection managers, done to reduce costs? Well, we have instituted statistical quality control programs (primarily to enable us to comply with government specifications), we have begun to use some automatic gaging equipment (often only because the gage manufacturer's salesman did a terrific selling job), and we have forced ourselves to become more familiar with statistical methods, even though the mathematics and terms used often taxed our patience. It is possible that many of the improvements instituted were primarily because of outside forces acting on us rather than because of inner drives to improve our jobs, and even so, the progress has been substantial.

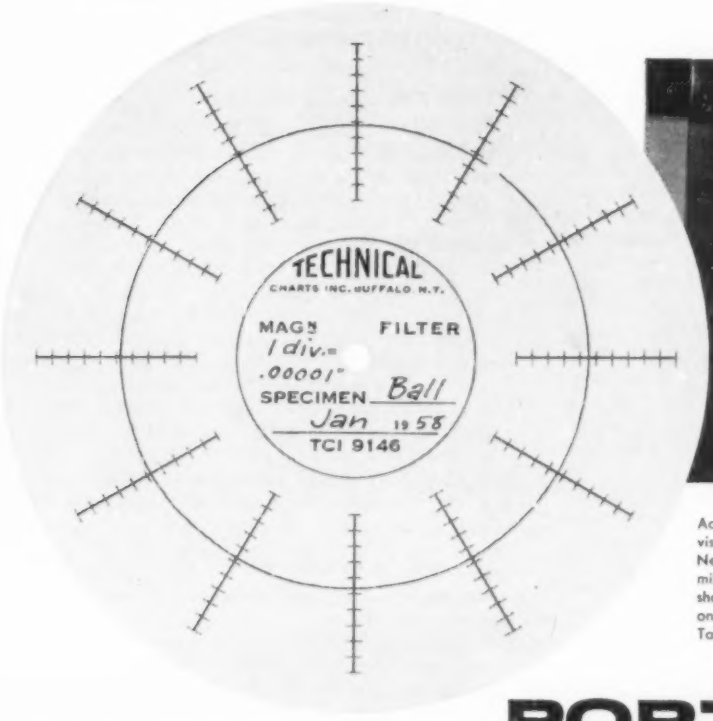
Now, what can *we* gain by taking cost reduction to heart and shaking it around like a dog rips at an old shoe? First of all, I believe, we should be considering the problem as one of profit improvement, instead of cost reduction—you and I can see a greater correlation between company profits and our pay checks than we can between costs and our checks. In other words, if we make a really significant contribution to our companies' profits, we can visualize recognition of this achievement in the pay envelope. In addition, all of us are working toward the highest job in management our talents will allow, and if our areas of responsibility show good planning and organization, we have additional chips in the promotion game.

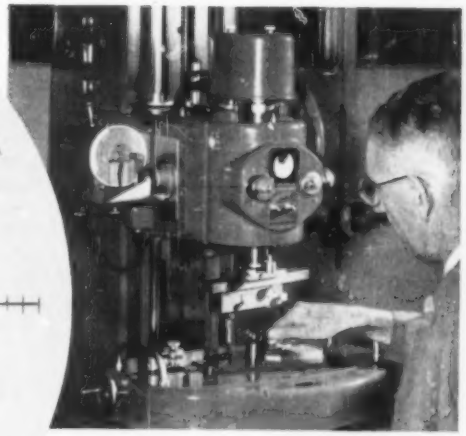
With the idea in mind of contributing to company profits, let us now take a look at applying work simplification to our everyday methods and see what it can accomplish for us. First of all, a goal is needed. I will go out on a limb and predict that if you seriously apply work simplification techniques, inspection expense can be reduced *at least* 30 percent. Furthermore, some of the exasperating daily problems such as employee grievances arising from difficult jobs or working conditions, inter-department squabbles caused by inspection delays, and management beratings for poor inspection and high costs, will be reduced significantly. To be able to measure the progress of your program, some records of inspection costs

Editor's Comments

The author was a speaker at an Inspection Management Clinic held by the University of Wisconsin in 1955. The editor was impressed with his straightforward presentation of a subject that should be of real concern to every Quality Control Supervisor. Mr. Barry was asked to prepare an article discussing this oft-neglected phase of inspection management. This is the first part of his two-part article on the subject of work simplification. (Part II of Mr. Barry's article will appear in a later issue.) You should find them thought provoking.

FACTS





Accuracy measured in millionths of an inch, made visible to the human eye. Steel balls, the heart of New Departure precision ball bearings, held to 5 millionths of an inch or less in sphericity. Graph at left shows sphericity variation of a ball on the order of one millionth of an inch (.000001") measured by Talyrond Machine. Graph radial divisions are .00001".

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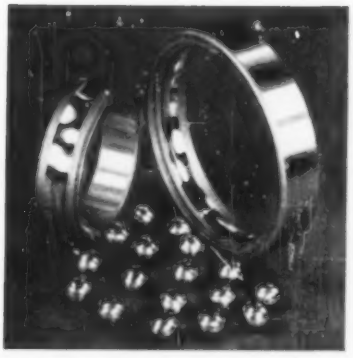

The extreme accuracy of New Departure ball bearing component parts is now playing a vital role in successful missiles for the Army, Navy and Air Force. Above —typical bearing parts, less separator —unretouched photograph.

A mechanism is only as accurate and reliable as the bearings supporting its moving parts. For the designer the problem is how to achieve the essential rigidity or *accuracy* of *location*, yet be assured of extreme *freedom* of *rotation*.

A "tip-off" to the solution lies in the chart above—super-precise steel balls, the heart of New Departure precision ball bearings. For, with balls held to 5 millionths of an inch or less out-of-roundness and other bearing parts finished with comparable care, such bearings can be mounted and *preloaded* to provide the hairsplitting exactness of location and *ease of rotation* required of the finest precision instruments.

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and criteria of progress are necessary. If this data is not now available, it can be obtained from the accounting group in your company.

"Now this all sounds pretty good", you say, "but how do we do it?"

Well, work simplification is nothing more than the organized application of common sense to find easier and better ways of doing work. Therefore, we are all equipped for this job without any training in advanced algebra or what have you, since the only tool we need is common sense, and we all have plenty of this.

How to Simplify Inspection Work

A. Pick Inspection Operation or Procedure to be Simplified

In choosing a job to be simplified, look over the department and select one inspection operation which is particularly troublesome. As an example, a job which is very time consuming and hence acts as a "bottleneck" to production, or one which frequently comes to your attention as being behind schedule might offer room for improvement, not only from the inspection time and cost standpoint, but might reduce the pressure the production department applies on you as a supervisor. If you have inspection operations which involve considerable gage set up (long "make ready" and "put away" time) or jobs which have considerable material handling required to accomplish the quality checks, these also would be good candidates for simplification.

In choosing the initial job or procedure on which to work it is important to consider the human relations aspects of the changes you may make. The inspector doing the work can be helpful in establishing a good work simplification "climate", however, if the person involved tends to be uncooperative or argumentative, your program may start off on the wrong foot and obtain publicity with the other inspectors which makes future work even more difficult. In this respect, many cases have shown that your program will be successful in direct proportion to the quality of your communications with the affected employees. A meeting with all of your employees prior to the start of the program at which you outline the reasons for the program, and more important, how it can benefit them through reduced fatigue, easier work load due to less complex operations, etc. can be of immeasurable benefit.

B. Eliminate the Operation or Break the Job Down

Now we are ready to dig into the operation itself for areas of simplification. Pull together all the pertinent dope on the operation in question—prints, previous experience charts, operation instructions, samples of good and bad parts, and any other material which will help complete the picture. First of all we should determine whether the entire operation can be eliminated or not. In many instances you will discover that work is being done which duplicates an inspection in another department. I can hear you saying to yourself, "Boy, how stupid does this guy think we are?" Well, I think you are all sharp fellows but I'll bet my next check against an old Landon button that this duplication occurs in your plant, too.

If the job cannot be eliminated in its entirety, then we must analyze it part by part. At this stage of the game help should be obtained from your methods department if you are not familiar with analysis of work elements, flow diagrams, etc.

STEP I—List the Work Elements

List in detail all the individual parts of the inspection job, such as—

1. Inspector removes casting from tote pan and places in checking fixture T2180.
2. Inspector moves height gage No. G6820 from aside position (see work place sketch) to part.
3. Etc.

STEP II—List the Equipment Used

Provide a list of all gages, setting block, flats, bench centers, etc. used including work benches, chairs or other equipment used by the inspector.

STEP III—Flow Diagrams and Sketches

Make a flow diagram (if applicable) of the material as it travels to and from the inspection station and note any unusual material handling such as long moves, additional pick ups, etc. Draw up a sketch of the actual work place showing location of raw and finished stock, position of gages and other equipment used, etc. This sketch should be in sufficient detail so that an unfamiliar person could completely reproduce the work place accurately if given the sketch and the equipment.

STEP IV—Discuss Job With Inspector

In the previously mentioned steps, many opportunities for discussing the work with the inspector doing the job will arise. At this point, summarize and filter his ideas already obtained and clarify any questions you may have for him. If the inspector has given you information you wish to check, make these checks with him, if possible, by asking him to show you the conditions he has mentioned. Much of the success of the entire project will depend on how well his ideas, thoughts and gripes are woven into the fabric of the simplified job, hence, the workers active cooperation is an asset of the first magnitude.

(Mr. Barry's article will be concluded in a later issue.)

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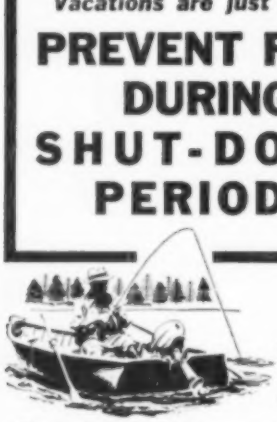

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Practical Aids

ELLIS R. OTT, *Editor*

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Control Board Measures and Displays Contact Quality

HAROLD HOFFMANN

Cannon Electric Company, Los Angeles, Calif.

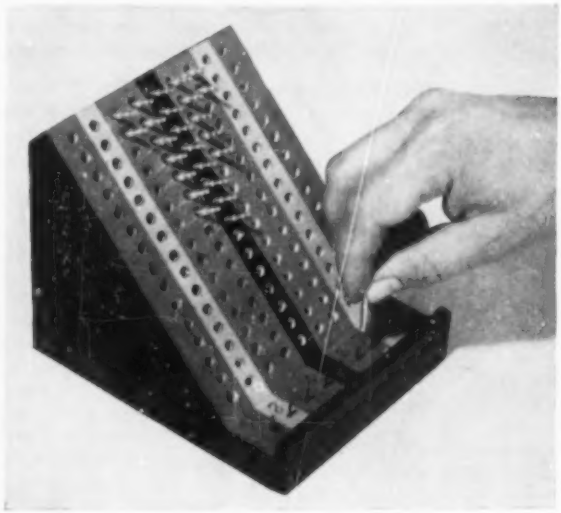


Figure 1—Contact Control Board

Permits Quality Control at the Machine by Operator

Testing the engaging and separation force of socket contacts for electrical connectors is facilitated by means of a *Contact Control Board*. The Control Board permits the machine operator to make a periodic check on the performance of her machine, and gives a physical model of the distribution curve of the work being performed. Thus, any need for adjustments are presented visually.

The Contact Control Board, as used at Cannon, is used to test the degree of crimp placed in the beryllium copper springs of connector socket contacts by a Clip Press machine, but the procedure is general and can be adapted to many applications.

The Control Board shows, in a highly graphic presentation, not only whether a test sample is deviating from the norm but exactly how much and in what manner it is deviating. It is used *by the machine operator* to perform a periodic check on the functioning of her own machine, and also, at less frequent intervals, *by the inspector*. To both operator and inspector it conveys a clear and verifiable picture of the test sample's distribution, without requiring any paper work, calculations, or interpretation of data.

The System In Operation

Once every 15 minutes, the operator stops her machine in order to check a sample of her work. Using the last 5 contacts she has turned out as her sample, she checks the (engaging end) inside diameter of each of these socket contacts, and makes a record using the Contact Control Board for this purpose. (See Fig. 1.) At the base of the board are nine precision-machined steel pins. These pins, numbered from 1 to 9, vary slightly in diameter in accordance with the acceptable limits for the inside diameter of the contact engaging end. The smallest-diameter pin is at the left (No. 1) and each succeeding pin increases in diameter by 0.001 inch.

The operator must find the largest-diameter pin over which the socket contact will fall by its own weight. The contact is then placed in a hole in line with that pin and at the same time assumes the number of that pin; e.g., a contact that will fall freely over a number 5 pin but not over a number 6 pin is classified as a number 5 socket and placed in a hole above the number 5 pin. The operator tries the center pin (No. 5) first, since this one has the highest probability of being a proper fit. If the contact does not drop over the No. 5 pin by its own weight, she tries the next pin to the left (No. 4), which is smaller, and continues to try each succeeding pin to the left until she finds one which will accept the socket contact. She then places this contact in a hole in the board directly above this pin, using the uppermost hole available in the column of holes above the pin.

If the contact drops over the No. 5 pin, the operator then tries each succeeding pin to the right until she finds one which will not accept the contact. She then moves back to the previous pin (the largest one which will allow the contact to fall over it by its own weight), and places the contact in the uppermost hole above this pin. The process is repeated for each of the 5 contacts tested.

Every 15 minutes the operator repeats this process with 5 more contacts, leaving the contacts which she had previously checked on the board. At the end of an hour's work, 20 contacts are distributed on the board. At this time the *inspector* checks 5 randomly selected contacts from the work just completed, and adds these to the 20 already on the board. Also the inspector may, if he wishes, re-check any of the contacts which the operator has placed on the board (in this way it is easy

to check on the possibility of an operator's bias at any time).

There will now be a total of 25 contacts on the board. The pattern in which they are arranged (see Fig. 1) gives a direct representation of the distribution curve for this sample.

Evaluating the Sample on the Board

The center pin (No. 5) represents the ideal situation. The column of holes over it is painted dark green. The next two pins in either direction (Numbers 3, 4, 6, and 7) represent acceptable tolerance values. The columns of holes above these pins are painted light green, to indicate acceptability.

The next pins to the left and right (numbers 2 and 8) represent values at the limits of tolerance. The columns of holes above these are painted in amber, a warning color. If one contact falls in the amber area, the operator calls her leadman to adjust the machine, but the work is not rejected. If two contacts fall in this area, either on the No. 2 or No. 8 side, the work performed since the last inspection period is set aside for further checking.

The outside pins (numbers 1 and 9) represent out-of-tolerance values. The columns of holes above these pins are painted red. If even one contact falls in this area, the leadman is summoned. The leadman determines the reason for the out-of-tolerance part, and makes the necessary adjustments to correct the entire operation. The parts which were made since the last inspection period are segregated so that the operator may check them further and rework them if necessary.

The inspector makes a record of each hour's performance as shown in the distribution of the 25 contacts on the board (the *operator* never uses a pencil in her checking). Then the inspector dumps the contacts from the board into the tote can with the rest of the finished work, and another inspection period begins.

Physical Description of Control Board

The board is of wooden construction with its face raised 45 degrees from the base. This face consists of 135 holes in 9 columns, 15 holes per column.

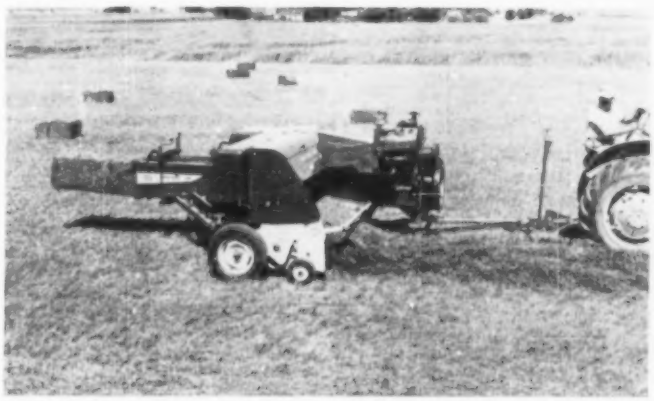
Each column is identified by a distinctive color and number. Each color column extends from the top of the face to the vertical edge of the base. Near the vertical edge of the base, nine precision-ground steel pins are mounted. Starting with the left-hand pin, each succeeding pin increases in size by 0.001 inch. The number 1 pin is the smallest pin, and the number 9 is the largest.

Appendix

Our purpose in using this Control Board at Cannon is to help the operator adjust her process to keep it on "target", with as little variation as possible, by the aid of this simple device. The standard deviation of this particular process has been determined to be essentially 0.001 inches. Consequently, each column of holes represents essentially a change of one-sigma; the red columns at the end correspond to points outside 3 σ limits.

If in a manufacturing process the purpose is not to control the process as closely to a target as possible but to hold it within specification limits which are appreciably greater than 6 σ, the board can be modified in much the way that modified limits are used on a control chart.

QUALITY CONTROL PROTECTS THE FARMER



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section briefs

ALLENTOWN-BETHLEHEM . . . The first annual 5th District All-Day Conference was a great success both financially and in the number of people who attended. The conference attracted 163 members, wives, and guests. Participating sections included Allentown-Bethlehem (host), Danville-Sunbury, Scranton-Wilkes Barre, Harrisburg, Philadelphia, Lansdale, and Trenton.

Featured speakers were: Dr. Ellis R. Ott, Rutgers • The State University; Miss Bonnie Small, Western Electric Co.; Mrs. Catherine Hock, U. S. Navy Department; and Professor Wallace Richardson, Lehigh University. Professor Arthur Gould of Lehigh University acted as moderator. The excellent talks were well received.

Society President C. E. Fisher spoke at the fine luncheon and congratulated the group on its endeavor. Mayor Donald Hock of Allentown, toastmaster, welcomed the Society, its guests, and its president.

BALTIMORE . . . On Mar. 4 the executive committee met at the John Hopkins University Faculty Club. One of the subjects discussed was nominating section members to the examining committee.

At the Mar. 17 meeting, St. Patrick's Day, a large turnout heard Dr. Max Astrachan of the Air Force Institute of Technology speak on the subject of sampling by variables. He discussed some of the fundamentals, described the construction of several plans, and demonstrated the use of MIL-STD-414.

Ballots were distributed so that members could indicate their choice for director of district 6. Candidates were: W. MacCrehan, quality manager of Bendix Radio; and J. Frederick Verigan, quality manager of Crown Cork and Seal Co.

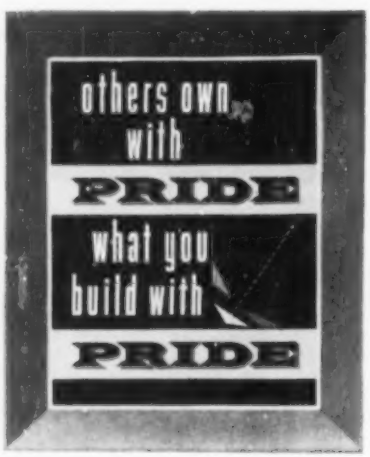
Prior to the meeting, the sixth of seven basic training sessions was conducted by Dr. David R. Howes of the Army Chemical Center, Edgewood. The subject was acceptance sampling by variables—which complemented the main talk of the evening.

BATTLE CREEK-KALAMAZOO . . . Dr. W. D. Baten, Michigan State University, presented a very fine lecture and demonstration with examples of "Acceptance sampling by variables." This whole presentation was spent in solving sampling problems. Dr. Baten is statistician for the Agricultural Experimental Station at the University and is also Book Reviews Editor for "Industrial Quality Control."

Dr. Aubrey Wylie of Michigan State University assisted Dr. Baten in the section sponsored QC course held earlier this year.

The above picture shows part of the group which made the recent 5th District All-Day Conference held in Allentown such a great success. Those shown are: (front row, left to right) Rev. Arthur M. Sherman, Church of the Mediator; Miss Bonnie B. Small, Western Electric Co.; Mayor Donald V. Hock; Mrs. Catherine Hock, U. S. Naval Gun Factory; (back row, left to right) Prof. Wallace Richardson, Lehigh University; C. E. Fisher, Bell Telephone Laboratories; David L. Hilder, Western Electric Co.; Dr. Ellis R. Ott, Rutgers • The State University; Prof. Arthur F. Gould, Lehigh University; conference chairman John Nemecek, Western Electric Co.

IT PAYS TO CONTINUALLY ADVERTISE



CHATTANOOGA . . . Three section members—J. B. Baity, DuPont; W. H. Corwin, Brock Candy; S. F. Torbett, U. S. Pipe—gave a first hand account of what QC is doing in local industry at the March meeting.

No formal program is scheduled for the summer.

CINCINNATI . . . On Mar. 18 our dinner guest speaker Paul Daniel of the Ed Brendamoor Sporting Goods Co. gave an interesting talk and demonstration on all forms of fly rod casting and spinning techniques. At the technical meeting later in the evening, L. K. Reitz of Eastman Kodak Co. spoke on "Fundamental applications of QC in the chemical industry."

March 23—members and wives toured the newest and most up-to-date Pepsi-Cola Bottling Plant here in Cincinnati.

Coming up—June 13 is our annual dinner-dance. A large turnout is expected for the annual presentation of awards and introduction of new officers.

Section member Wm. Barker, General Electric's AGT Division, spoke on "Organizing for quality" at the recent 6th annual industrial clinic for QC held in Milwaukee.

CORNING-ELMIRA . . . The section wishes to express its thanks to Prof. Paul C. Clifford, Montclair State Teachers College, for his fine talk "Control charts without calculation." The meeting was held Mar. 10 at the Hotel Langwell in Elmira and was attended by 40 members and guests. Prof. Clifford not only explained the use of median control charts but also discussed the use of control charts in American industry today.

DALLAS-FORT WORTH . . . Once again we close the book on a highly successful QC symposium. This symposium was successful in terms of attendance (more than 260), income, and most importantly stimulation of interest in the application and advancement of QC technology. Many of the attendees were from fields other than QC and many local business firms were represented at a section event for the first time.

Congratulations to the officers who will lead the section during 1959-60. They are: chairman—Charles L. Scarborough, TEMCO; vice chairman—Roger W. Anderson, Texas Instruments; secretary—Eugenia R. Wingfield, Convair; and treasurer— Glen H. Parmeter, Convair. The new directors are Dr. John L. Worthham of Texas Christian University and Robert D. Maulden of Williamson-Dickey.

DELAWARE . . . The March meeting was highlighted with an after dinner address by Prof. Wallace J. Richardson of Lehigh University. Prof. Richardson spoke on "Work sampling," where and how it can be used effectively in industry, and some of the statistical techniques employed in analyzing the data.

Prior to dinner, R. W. Kennard of the DuPont engineering department, conducted a one-hour clinic. His topic was "Regression analysis—design and case study."

DENVER . . . The Mar. 26 meeting was held at the Denver Public Library. Three films were shown concerning QC applications at the New Departure Bearings Company.

EVANSVILLE-OWENSBORO . . . A very enjoyable evening was had by the group at the Mar. 17 meeting held at the Moonlite Bar-B-Q Inn in Owensboro. Fred J. Berkenkamp, QC engineer with the General Electric Co., spoke on "The new total QC."

GREATER DETROIT . . . W. J. Gallagher, Jr., section vice chairman, spoke on "Statistics and realistic tolerances" at

One of the highlights of the recent 2nd Annual Automotive Division's Conference was the paper presented by B. I. Raysor, general manufacturing manager, Harrison Radiator Div., GMC. Fran Newton of the Ford Motor Co. is shown congratulating Mr. Raysor (right) for his fine talk on "The High Cost of Goofing." This conference was cosponsored by the Greater Detroit section.

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"Pontiac with wide-track wheels is the best combination of ride . . . handling . . . performance and styling of any '59 car"

—The Editors of Motor Trend Magazine

In making its annual automotive award, the staff of Motor Trend Magazine, leading automotive publication, tests and evaluates all new cars. Here are quotations from the April 1959 issue:

"The stability of the 1959 Pontiac is the outstanding automotive advance of the year. Everyone considering a new car should experience it."

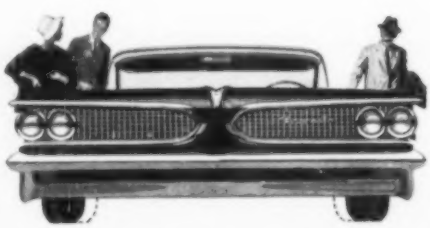
"It's the best balanced passenger car in America. We firmly believe that in moving the wheels farther apart, to develop the widest stance of any American car, Pontiac has created an entirely new sense of balance and handling security."

"Pontiac's lines are clean, simple and beautiful. It has a fleet look, a trim appearance. The wide wheel design contributes greatly to its over-all integrated styling. Any comparison with narrower track cars readily shows the difference."

"For the economy-minded, an efficient new engine. The new 420E Tempest economy engine offers remarkable performance along with exceptionally high mileage while operating on regular grade gasoline."

"Pontiac is again tops in performance, based on our extensive road testing. Acceleration is outstanding, yet the engine is unusually quiet and smooth."

This high acclaim and important award from Motor Trend is another of the many exclusive selling advantages enjoyed by Pontiac dealers.



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the recent 6th industrial clinic for QC held Mar. 20 in Milwaukee.

The 2nd annual automotive division conference theme of "The industries challenge—higher quality" was well presented by key executives representing all phases of industry. This conference, cosponsored by the section in cooperation with the University of Michigan mathematics department, should be deemed a tremendous success education-wise. Each paper presented was of a practical nature. The QC programs of the companies fortunate enough to have representatives in attendance will be bolstered by the knowledge gained at this conference.

GREATER MUSKEGON . . . Our annual outing at the Mona Lake Boating Club was held Mar. 12. Forty-one members and guests thoroughly enjoyed the family style "boiled shrimp" dinner. Everyone had more than their share of the tasty delicacies. The dinner was more enjoyable as the meeting was informal and slacks and sport shirts were in order. Harold Sprengel of the Detroit Arsenal discussed the "Department of Defense quality assurance program," which was very informative. He outlined the problems of supplying, testing, and keeping track of millions of articles used by the Defense Department throughout the world as well as methods used to process them. The use of IBM cards has accelerated the handling of myriads of data and complaints.

The annual election of officers followed Mr. Sprengel's disertation and completed the evening's program. Elected for the 1959-60 year were: Merrill Bailey, Larry Long, Ray Porter, Basil Smith, William Poe, Ed Fortenbacher, and Elwood Presley.

HAMILTON . . . On Mar. 12 a large number of members and guests visited Proctor & Gamble where we were treated to a very interesting tour of their ultra-modern soap manufacturing plant. Our very sincere thanks to the officers of the company (Messrs. Simpson and Shanahan) and the guides for a most enjoyable and instructive tour.

Prior to the tour, a short business meeting was held. Chairman W. C. Luton and past chairmen Miss M. Baskerville and H. E. Markle were appointed to present a proposed slate of officers for 1959-60.

HAMILTON-MIDDLETOWN . . . The attendees at the March meeting were subjected to a bitter disappointment. Due to the snow storm, the guest speaker's plane was unable to land.

HARRISBURG . . . The final meeting of the year will be held at the Stone Barn in Millersville. A delicious chicken barbecue dinner will be served on the picnic grounds and outdoor recreation facilities of all types will be available.

Our new officers will be duly installed at a brief meeting after which numbers will be drawn for both door prizes and 100 percent attendance prizes.

Members are cordially invited to bring guests.

HARTFORD . . . A panel discussion on "The management of inspection" was the highlight of the Mar. 17 meeting. Members of the panel were: Chester Hoffman (chairman), Royal McBee Corp.; Truman Read, Hamilton Standard; Howard Parsons, Fafnir Bearing Co.; and Albert Aubin, Underwood Corp. Questions from the audience led to discussions of such topics as: responsibility for quality, relationship between inspection and QC, who makes decisions, how to rate the performance of an inspector, QC as a service unit, and organization to provide correct methods.

HUNTSVILLE . . . The March meeting was held at the Lyon's Hotel in Decatur. It consisted of dinner and the election of officers for 1959-60. After the meeting the group made a plant tour of Wolverine Tube, Division of Calumet & Hecla, Inc.

KANKAKEE-JOLIET . . . C. O. Bunch, chief works chemist at Union Carbide Chemical Co., was guest speaker at the Mar. 3 meeting. He spoke on "Statistical control of fill in canning antifreeze." He discussed the results of an investigation to select a method of controlling fill. Several alternative methods were also discussed.

LOS ANGELES . . . March was an exciting month starting with a field trip to Point Mogu on Mar. 5, an exhibit at the San Fernando Valley Industrial Show run by Ray Primmer of Hydro-Aire, and the regular meeting speaker, John J. Riordan, of the Department of Defense.

LOUISVILLE . . . The Mar. 9 meeting took place at the University of Louisville Speed School with 25 members present. Mr. Lipps announced that the section still remains 24th nationally and second in the district. Al Green, nominating committee chairman, submitted a list of names which are to be voted upon to fill the executive offices for 1959-60.

WILLIAM C. VISSING

Just two months ago it was our pleasure to announce the election of William C. Vissing of the Indianapolis section to the grade of Fellow. This month we must regretfully report Mr. Vissing's sudden and untimely death on April 5.

Bill was graduated from Michigan State University in 1946, receiving a B.S. degree in chemical engineering. He was head of the pharmaceutical inspection control department, Eli Lilly and Co., and had been employed with the company for 12 years. He became interested in the activities of quality control and our Society in 1952. He was very active in the administration of the Indianapolis section and the Society since that time, serving in various capacities including that of director of the Society in 1957-58.

The section and the Society feel a very personal loss at his untimely passing. Our sincere expressions of sympathy go to Bill's wife and fine children.

The speaker of the evening was one of our own section members, Paul Dysert, who spoke on "Stock market analysis." He gave an interesting presentation of how statistics may be applied to stock and securities analysis showing what effects random and human forces have on the analysis. We thank him for his information and sound advice on this subject.

METROPOLITAN . . . On Mar. 19 the section held its unique and long anticipated "Buzz session." The response was enthusiastic and highly gratifying. The presence of approximately 150 members and guests testifies to the popularity of this type of session.

The meeting format called for those in attendance to seat themselves at tables designated "mechanical," "electronic-electrical," and "chemical-pharmaceutical." Charles D. Ferris, QC manager of Mohasko Industries, Inc., set the theme and direction of the meeting through his keynote talk on "Selling QC to management."

THE FIRST HOURS OF TOMORROW

In what area of medical science will tomorrow's big "breakthrough" come? Virology? Coronary and renal disease? Mental health?

For the past 20 years we've watched research roll back one problem area after another. But research is already projecting today's accomplishments into tomorrow's benefits.

We can expect medical progress to continue as long as research recognizes today as the first hours of tomorrow.

MERCK SHARP & DOHME
Division of Merck & Co., Inc.

"Research for the Conservation of Life"

The tables, under their individual chairmen and co-chairmen, then discussed "Selling QC to foremen" and "Quality incentives." The summary pointed to job security and reduction of scrap as QC's best salesman.

The success of this session stems from the fact that it provides for a practical exchange of ideas by management and QC people facing and solving the same problems that are encountered by all of us.

Oh yes! Coffee and cake were on the house.

MID-HUDSON . . . The March dinner meeting was held at the Nelson House in Poughkeepsie with 52 members and guests in attendance. E. C. Harrington, Jr. of Monsanto Chemical Co. was the guest speaker. His subject was "Response surface experimentation" which concerned running of dimensional experiments with more than one variable. His talk was well received and was followed by a question and answer period.

The annual social evening will be held at the Germania Hall in Poughkeepsie on June 2.

MINNESOTA . . . R. E. Meyers, reliability statistician of the Minneapolis-Honeywell Aero Division, was guest speaker at the Mar. 18 meeting held at the Coffman Memorial Union on the University of Minnesota campus. The subject of his talk was "The state of the art of reliability."

MONTREAL . . . Miss M. N. Torrey, Bell Telephone Laboratories, presented a very interesting talk at the March meeting. Her subject "Selection of samples for a purpose" illustrated ways of selecting samples for various purposes such as product acceptability, evaluation or improvement, and controlling a process. As a momento of her visit, the section presented Miss Torrey with a French petit-pointe evening bag.

The annual business meeting and dinner is to be held on June 3 in the Canadian Room (La Salle Canadienne) of Windsor Station. The meeting will feature an outstanding speaker.

No meetings are scheduled for the summer months.

MUNCIE . . . March 19 marked the appearance of James W. Christy, director of QC of the Nu Tone Co. His subject was "Administration of a QC program and measures of performance." We are very grateful to Jim for the fine job he did on such short notice. (Grateful too, for Leon Bass' help in the emergency.)

PHOENIX . . . The March meeting was held at the Arizona Public Service Building. Gene Schwetz spoke on QC and statistical analyses as related to foundry practices. His talk was followed by a movie on vibration testing.

The section is progressing with its plans for hosting the Western Regional QC Conference in October. The agenda of speakers, their talks, and company displays give every indication of an outstanding conference.

PITTSFIELD . . . William Carter, industrial consultant, was seminar leader of the afternoon-evening session held Mar. 11 at the Stanley Club. The subject of the seminar was "Practical management of a QC program."

An inter-relationship between QC and other departments in a manufacturing organization was developed by Mr. Carter and the attendees. Time was devoted to defining the ideal functioning of QC with design engineering, accounting, production control, industrial engineering, purchasing, employee relations, production, and management.

PORTLAND . . . The installation of officers will take place at the final meeting of the season to be held at the Lucky Lager Tap Room in Vancouver on June 2. Members not interested in the congenial atmosphere of free beer, etc. should attend for the purpose of supporting the new officers. The section has more members now than ever before in its history, but there are duties for each and every member. This is the annual "Ladies' Night" so all members are invited to bring their better-half.

RHODE ISLAND . . . Charles A. Bicking, The Carborundum Co., was guest speaker at the Mar. 19 meeting. His subject was "SQC in manufacturing."

ROCHESTER . . . On Mar. 3 the gaging & measurement sub-group was addressed by Dr. Francis E. Washer, National Bureau of Standards. His topic was "Evaluation of distortion of photographic lenses."

(Continued on page 70)

Quality Control Begins with Research and Development

Through the statistical approach to quality control and progressive development, Johns-Manville has zealously maintained its reputation for quality.

J-M Asbestos Mill World's Largest

As evidence of this research and development Johns-Manville announced late in 1954 the dedication of what would be the world's largest asbestos mill. In fact, this mill when only half completed was the largest in the world. It is now completed and in full operation.

Illustrated here is the mill building located at the J-M Jeffrey Mine at Asbestos, Canada.

Through rigid quality control and the most modern equipment for the milling of high quality asbestos fibres, Johns-Manville is meeting the increasing demands for the higher grades constantly required for new product developments for both home and industry.

Providing a production capacity of 625,000 tons annually, this recently completed asbestos mill provides twenty-two and one half acres of floor area, is 12 stories high.

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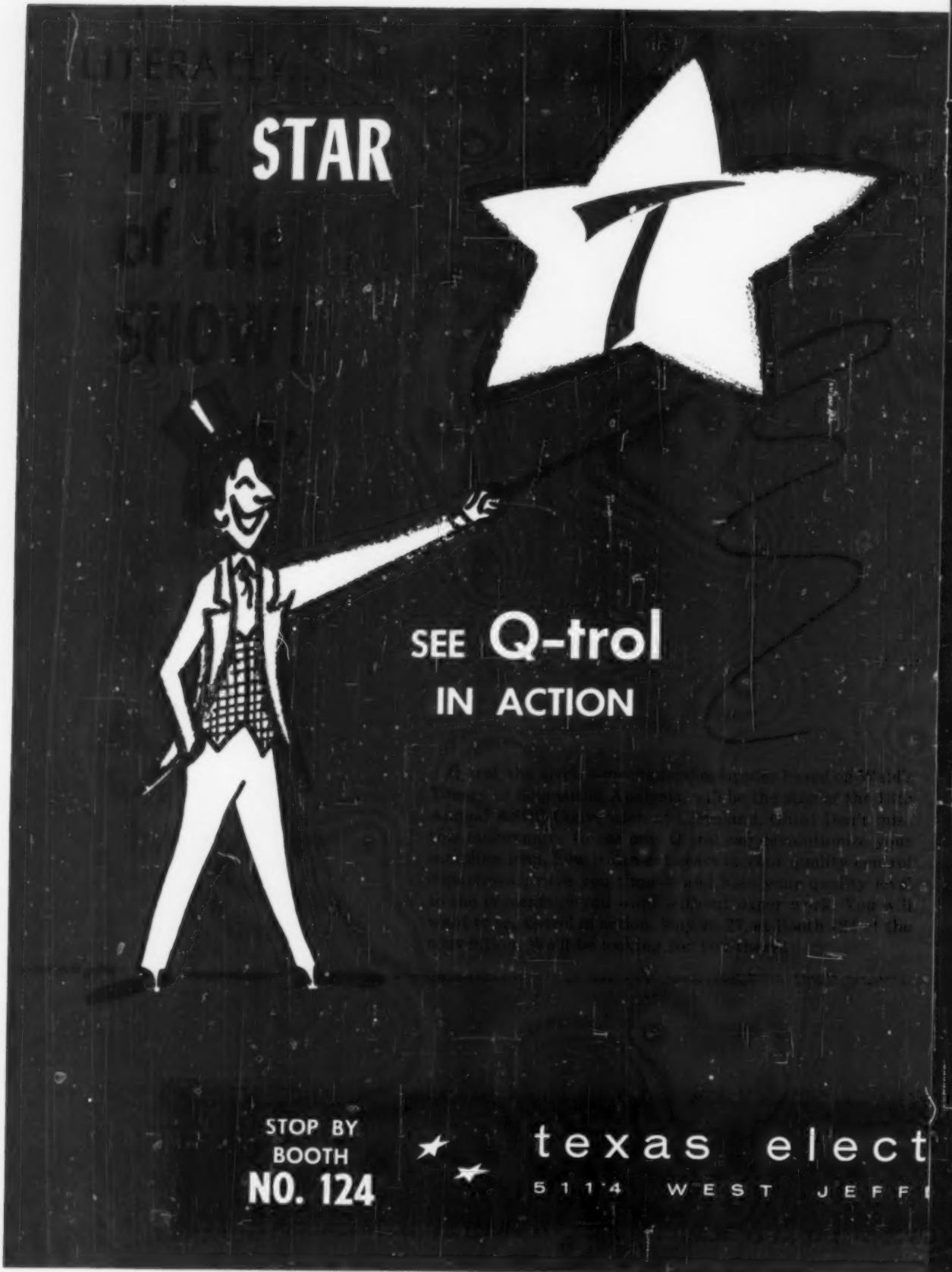
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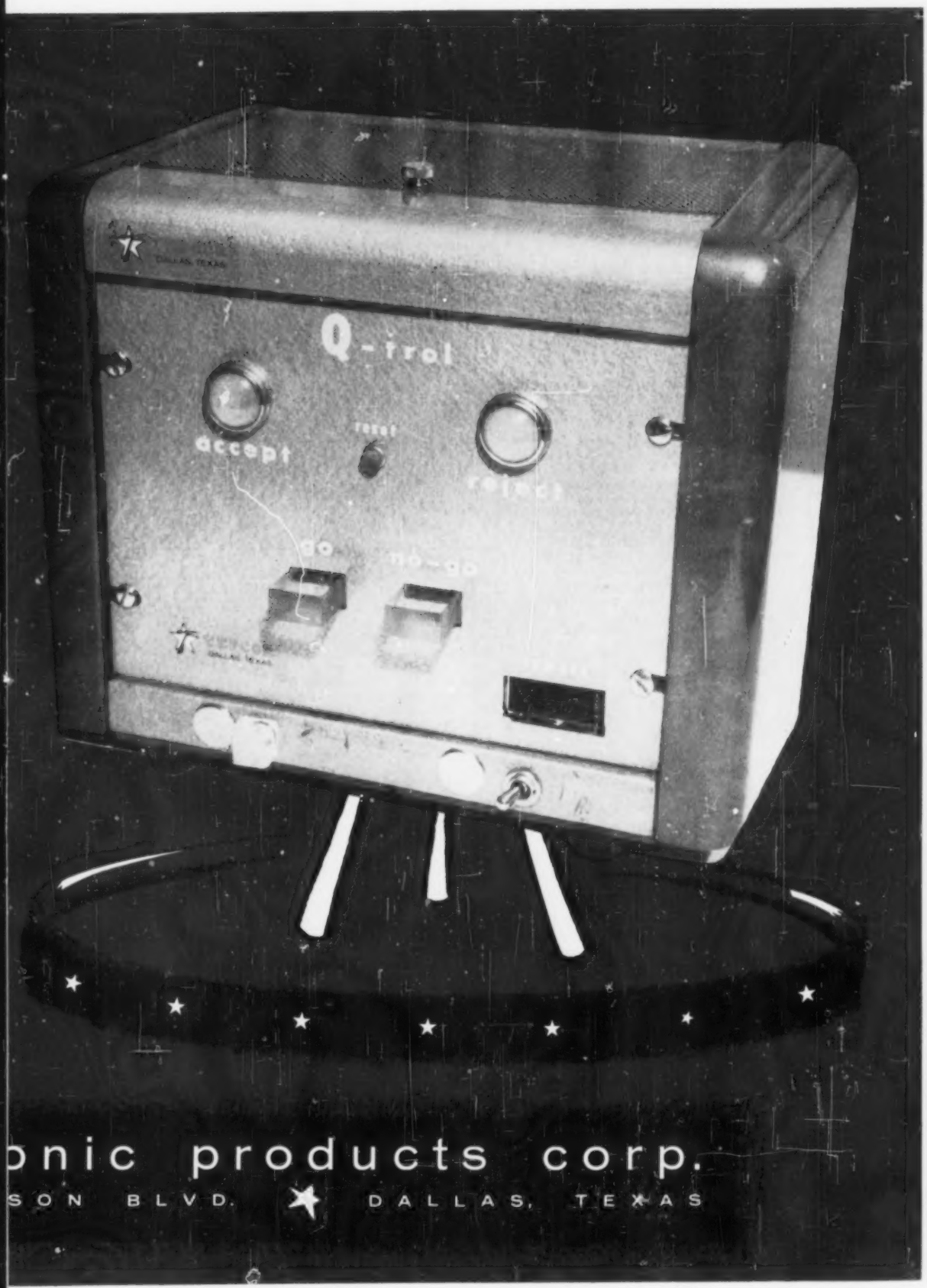
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SON BLVD. DALLAS, TEXAS

(Continued from page 66)

The highlight of the season's activities occurred on Mar. 26. The 15th annual clinic brought over 700 people to 18 meetings. The luncheon meeting was addressed by Dr. Cornelis W. De Kiewiet, president of the University of Rochester. Clinic general chairman Carl Speitel, Bausch & Lomb Optical Co., and his staff did a magnificent job. Many thanks for assistance go to: Russel C. McCarthy and Richard J. Toole and staff, Industrial Management Council; Dr. Howard Anderson, Dr. S. Lee Crump, and Dr. Robert McCambridge, University of Rochester; and to the Rochester chapter of ASA.

ST. CHARLES . . . G. S. Evensen and W. R. Fischer, General Electric Co., gave an outstanding presentation of the subject "Professional QC engineering and management" at the March dinner meeting. They outlined what it is and how it has been successfully achieved at the GE plant in DeKalb.

ST. LOUIS . . . The March meeting was held at the Golden Fried Chicken Loaf Restaurant. The speaker of the evening was Richard Bingham, Jr. of the Carborundum Co. His topic was "What's behind experimental design."

SACRAMENTO . . . Ken's Red Barn was the scene of the January meeting. Harry D. Greenwood, Aerojet-General Corp., spoke on "The importance of calibration in respect to assurance of a top quality product."

The February meeting was held at the Chuck Wagon. The standing-room-only sign was displayed early in the evening and the group was well rewarded. Prof. W. Grant Ireson, Stanford University, presented "Education for reliability."

The meeting of Mar. 12, held in downtown Sacramento at Sam's Hofbrau, was particularly impressive. Seventy-seven members and guests heard an old friend, Dr. H. G. Romig, speak on "Installing an effective quality engineering program." Dr. Romig, Hoffman Laboratories and a Society Director, will be long remembered by his audience.

Election of officers for the coming year is underway. Loyal secretary Jeanette Ashton has mailed the ballots. Only one candidate is unopposed. Aerojet's George Smith is assured of the office of chairman and fearless leader.

SALT LAKE CITY . . . The theme of the Mar. 17 meeting centered around the gathering and analysis of data. John F. Boyd, Sperry Utah Engineering Laboratory, presented the educational phase—"The basis of analysis of data obtained in a process or test." By means of appropriate examples he highlighted the two principal problems of statistical inference: (a) that of testing formulated hypothesis, and (b) that of estimation.

The guest speaker was H. B. Wishard, U. S. Steel Corp. He pointed out that progress being made in automation in industry was closely tied-in with automatic data pickup and electronic equipment for compiling and analyzing this data. He stated that present day amount and reliability of data had greatly increased. He opinioned that advancements in data gathering, compiling, and analysis would have to be greatly accelerated if it is to keep pace with the progress being made in automation.

SAN ANTONIO . . . James L. Coburn, Convair-Fort Worth, was the guest speaker at the Mar. 10 meeting. Mr. Coburn presented a paper on "Modern reliability programs." It was centered around the reliability program in effect at Convair for the B-58 program. The paper was supplemented with color slides that depicted the actual concepts of the program in use with personnel in the act of carrying-out the various phases entailed in the program. In addition to this highly interesting paper, Mr. Coburn spent an additional 30 minutes in highlighting a talk on "QC for the 200 and under manufacturing firms." The section is indeed grateful to Mr. Coburn for the time and effort expended in granting us this opportunity to obtain vital data on such timely topics.

The executive committee met during March to discuss business affairs of the section, a membership booster campaign, section by-laws, and preparations for the annual picnic and installation of new officers. The latter event will be held June 18 at the Lone Star Brewery Co.

SAN DIEGO . . . At the March meeting the section enthusiastically endorsed the slate of officers presented by the nominating committee. There were no additional nominations.

Beginning July 1, the following men will be charged with the task of carrying forward the dynamic growth of the section: chairman—H. E. "Gene" Fleming, Rohr Aircraft Corp.; vice chairman—L. I. "Russ" Medlock, Convair; sec-

Call to Authors

The 6th National Symposium on Reliability and Quality Control, jointly sponsored by ASQC, IRE, and AIEE, will be held Jan. 11-13, 1960 at the Hotel Statler, Washington, D. C. Authors desiring to submit papers for presentation at the symposium must submit abstracts by June 15, 1959.

All abstracts submitted must consist of:

1. **Title of paper—limited to 50 letters including spaces.**
2. **Author's name, position, company or military affiliation. (Where paper is joint work, indicate who would present the paper.)**
3. **Abstract—limited to two (2) pages, approximately 800 words or less.**
4. **Ten (10) copies for review circulation use by the committee.**
5. **Abstract will be prime reason for final paper selections. Indicate: new approach, success achieved, confirmation of theory.**
6. **Ten (10) copies of biographical sketch of each author or speaker.**

Notification to authors as to status of acceptance will take place during the week of July 20. By Sept. 14 detailed instructions will be sent to authors and final papers must be submitted by Oct. 15.

Max M. Tall
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Orlando-Cape Canaveral Section and Cape Canaveral Reliability-Quality Control Club Hold Joint Meeting

The joint meeting of the Orlando-Cape Canaveral section of ASQC and the Cape Canaveral Reliability-Quality Control Club was held at the Patrick AFB Officers Club on Feb. 12. An excellent dinner was served buffet style and approximately 140 well fed, contented members and guests settled back to listen to the evening's program. Dr. Benson introduced the chairmen of the respective organizations—Jack Kidwell of the ASQC section, Martin-Orlando; and Phil Betts of the Cape Club, Bell Labs. They in turn introduced their officers and committee chairmen.

The ASQC educational program, beginning Feb. 25, was announced by Betty Crocker. Tom Willey, vice president and general manager of Martin's Cocoa Division, key-noted the program.

The featured speaker was General Don Fleckinger who spoke on the "Human component relative to space travel."

The tremendous success of the joint meeting was a tribute toward the hard work of those who participated in its organization.

Here are the main participants of the joint meeting. Left to right—Tom Willey, Brig. General Fleckinger, Phil Betts, and Jack Kidwell.

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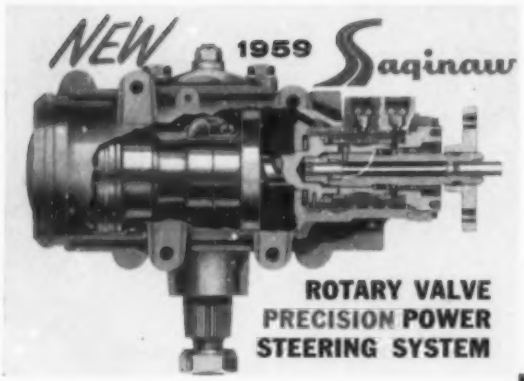

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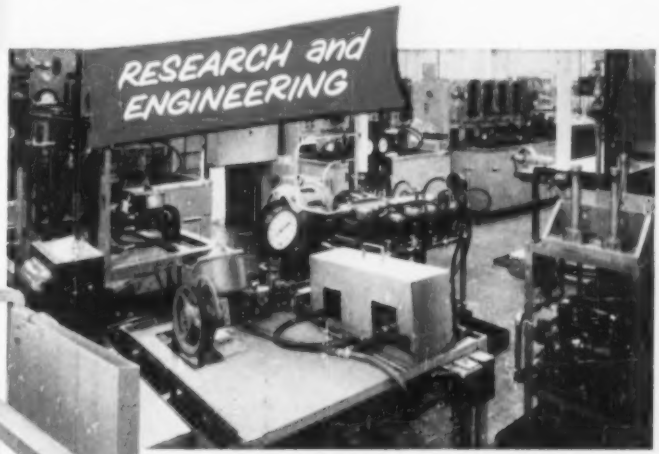

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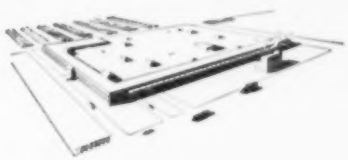

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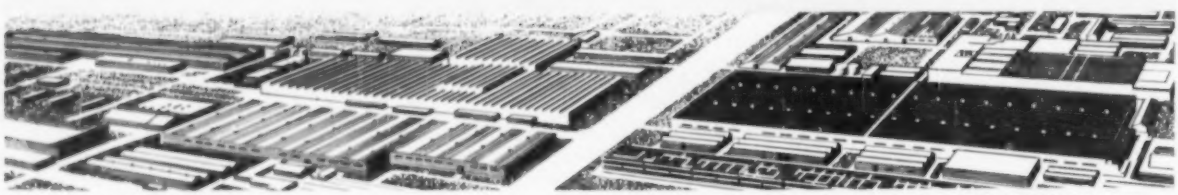

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retary—"Walt" Dibblee, San Diego APD; treasurer—"Bob" Knight, Ryan Aircraft Corp. We are sure of their capability and determination and we wish them every success.

SOUTHERN CONNECTICUT . . . The section very happily hung up the S.R.O. sign (standing room only) at its March meeting held at the Treadway Inn, Norwalk. Attendance was well over the 280 mark. The speaker of the evening was C. G. Shelly, DoALL Co. Mr. Shelly, who is a well known scientist, presented "The Story of the Cutting Edge" and used a 43 foot panorama with his talk to dramatically pace those attending through a million years of progress, which without a doubt made a lasting impression on all.

Everyone attending came away from this program with a better understanding of the part we QC men play in keeping America competitive in this, the new space age.

SOUTH TEXAS . . . J. L. Coburn presented a very interesting talk with graphic presentations at the Mar. 11 meeting. His topic was "Quick and easy QC for small manufacturing companies."

STATE UNIVERSITY OF IOWA . . . The winter meeting was held during March at Galesburg. Everyone enjoyed a fine tour and operations discussion of the Midwest Manufacturing Corp.

R. A. Maass and L. B. Crawford, Admiral Corp. quality managers, gave excellent slide illustrated talks on their QC procedures in television and communications equipment manufacturing.

Dr. C. C. Craig of the University of Michigan presented a thought provoking talk on a simple sequential variable sampling procedure.

The next meeting will be held at the State University of Iowa on June 4-5. Dr. L. A. Knowler and his able assistants will present "MIL-STD-414: theory and applications." This will also be the annual election of officers meeting.

TENNESSEE . . . At the Mar. 19 meeting plans were laid for many of the coming year's activities. Important among these was the decision to form a subsection in the Nashville area with the hope that eventually a new section will be established there.

The section wishes to acknowledge the fine work of its former members in establishing the new Northeast Tennessee section and to offer our best wishes for the future.

Prof. Bob LaForge presented a talk on "Acceptance sampling" at the Chattanooga All-Day Conference recently.

The section is proud of six of its members who recently were advanced to the grade of senior member. They are: Hershel Buchanan, Morristown; Earnest Freudenthal, Nashville; William Herrgen, Gallatin; Shirley Mackey, Knoxville; and Eric Johnson and Roberta McCutchen, Oak Ridge.

TUCSON . . . L. P. Gideon, Hughes Aircraft Co., spoke on "The professional quality engineer" at the Mar. 26 meeting. Mr. Gideon, chairman of the District 16 professionalism survey committee, discussed the results of the survey and suggested a plan for awarding certificates in the field of QC by major universities similar to awards now given by the University of California in the field of industrial relations. He indicated that QC should not be limited only to engineering applications since about 1/6 of the Society membership is engaged in engineering.

Joe Loesch has been named section vice chairman by the executive board to replace Warren Clemens who transferred to the Los Angeles section.

Chemical Division News

The Division met in St. Louis on Feb. 20-21. A full quorum was present. A committee, headed by Dr. C. T. Shewell, was appointed to review the publication policy of the Division now that *Technometrics* has been safely launched and to recommend a future policy.

The annual meeting of the Division will be held in Cleveland during the Convention on Monday night. Details will be in *C. D. News* and will also be announced at the Convention.

The "Statistical methods for process development" course will be held at the University of Chicago June 15-25. Instructors will be Dr. G. E. P. Box, Dr. J. S. Hunter, and Dr. W. G. Cochran.

WILEY BOOKS

OPERATIONS RESEARCH

Methods and Problems

by **MAURICE W. SASIENI**, Case Institute of Technology; **ARTHUR YASPAN**, Standard Oil Co.; and **LAWRENCE FRIEDMAN**, M & M's Candies. A really basic text in the methodologies of Operations Research. Mathematics is the watchword here. Theory and techniques are illustrated in solutions of many problems—production scheduling, inventory control, purchasing, maintenance, merchandising, finance, etc. Linear programming is given a clearer treatment than in most books.

1959. 316 pages. Prob. $9.50

ELEMENTARY DECISION THEORY

by **HERMAN CHERNOFF**, Stanford University, and **LINCOLN E. MOSES**, Stanford University School of Medicine. The first really basic book built around the theme of decision theory. Because many books are now so far outdated, the authors concentrate on what is new: 1) statistics is shown clearly as the science of decision making under uncertainty; 2) fresh examples explain various problems; 3) included is a chapter on utility theory, vital in economics and statistics. Many new ideas are presented—clearly—and all are summarized at the ends of chapters.

1959. 364 pages. Illustrated. Prob. $7.50

SAMPLING INSPECTION TABLES

Single and Double Sampling, Second Edition

by **HAROLD F. DODGE**, Rutgers University, and **HARRY G. ROMIG**, Hoffman Electronics Corp. A vastly revised, improved edition of this classic, including tables for sampling all kinds of products. This edition contains the probability of acceptance curves called "operating characteristics;" material on destructive inspection; forms for statistical analyses and for control on the plant floor.

1959. 224 pages. $8.00

THE ANALYSIS OF STRAIGHT LINE DATA

by **FORMAN S. ACTON**, Princeton University. For the reader who needs an orientation on the philosophy of choosing a statistical model and its influence on subsequent analysis. In short, this book deals with the analysis of experimental data that can be described in terms of a linear relationship. Stress is on matching the method of analysis to the kind of information desired, and the influence of the assumed model on the success of the analysis. Short-cut computational techniques are stressed.

1959. 267 pages. Illustrated. $9.00

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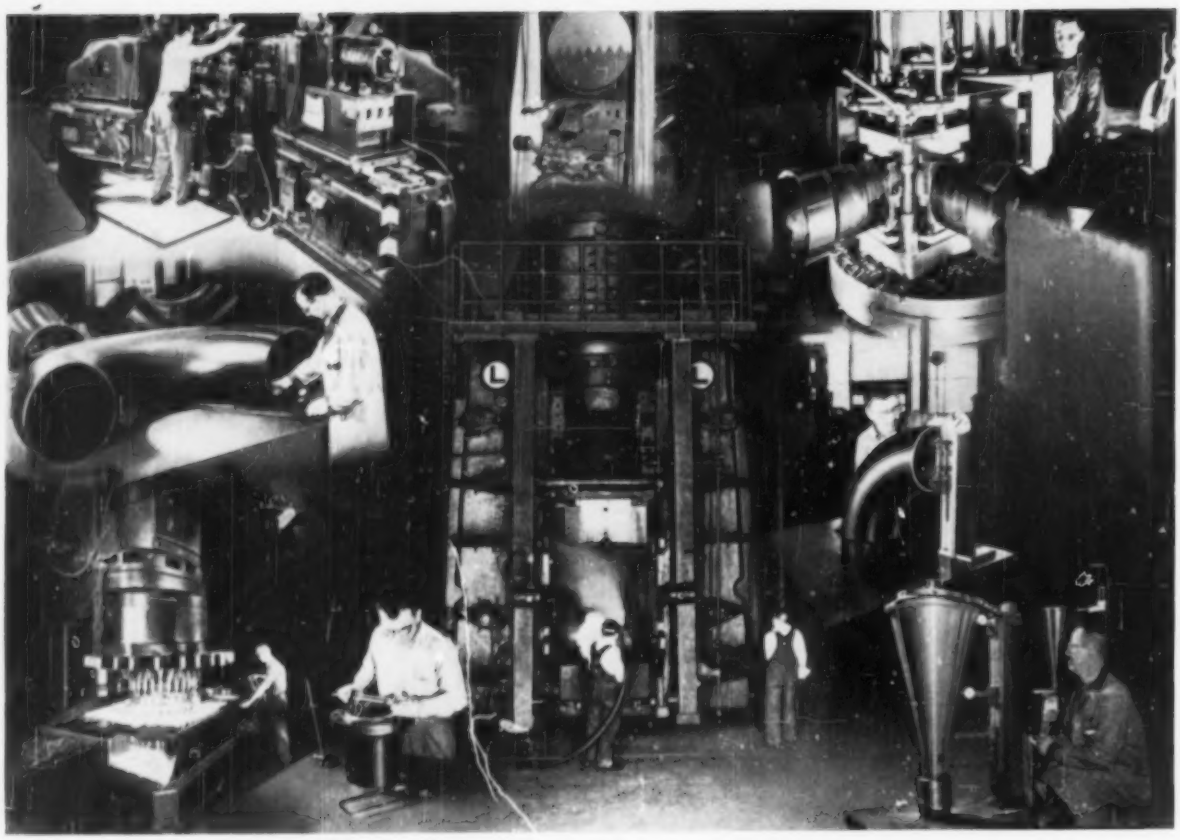

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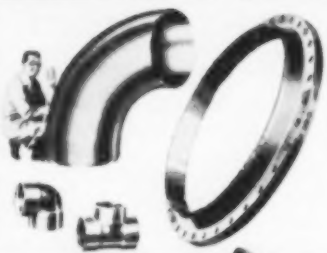

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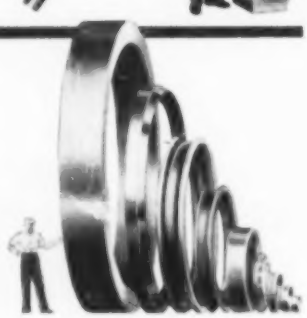

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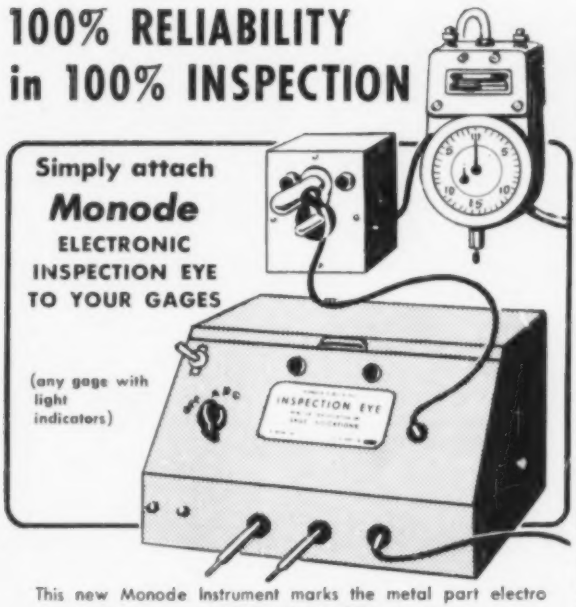

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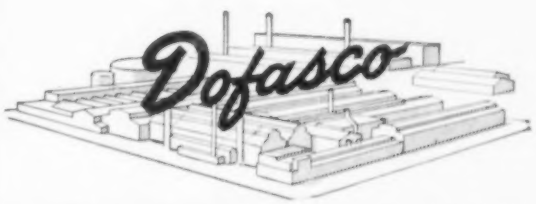

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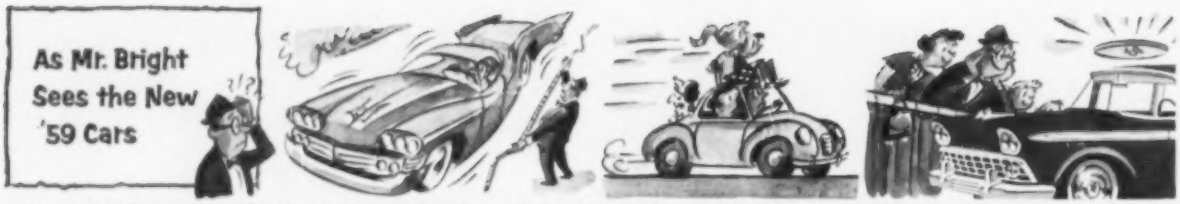

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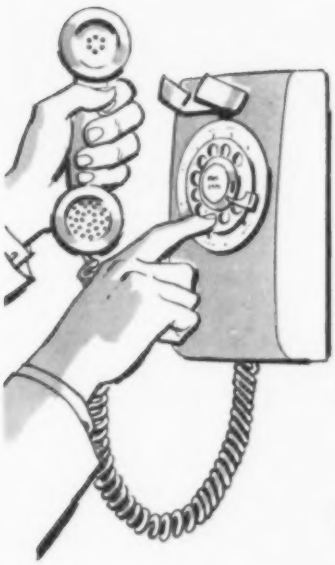

"FIRST CALL, THEN FIX"

A quality control slogan that keeps production standards high

Good Quality Control depends on good communications. This is particularly true at Continental, since can bodies are turned out faster than the eye can see. Close teamwork and communications between the Operating and Quality Control Departments is a must. Any deviation in standards must be checked immediately or spoilage can be fantastic. Our operating and quality control people accept this responsibility with a will. Their working motto is: First stop the line . . . alert Quality Control to prevent defects from leaving the production area . . . find out what is wrong on the line, and then fix.

Before a trial run, machinery is inspected to make sure it is at its top quality level — from slitter to double seamer. Every station is set up as if it were a separate machine. During trial runs, cans are stripped, structures exposed and studied, and alterations made as required.

During regular production, cans are pulled off the line, measured, stripped, and studied again to assure that production standards are being maintained. In addition, quality control inspectors take a sampling of finished cans before they leave the plant.

Quality control is a vital facet of U.S. industry. No one appreciates it more than Continental Can Company.

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Canadian Division: 5595 Pare St., Montreal, Que.
Cuban Office: Apartado #1709, Havana

What's New?

ROY A. WYLIE, *Editor*
Ampex Corporation

P-3-11—An ultra-sensitive moisture indicating instrument with roller type electrode for use on moving paper rolls has been announced by Moisture Register Co. The new Model PM, incorporating five stages of sensitivity, solves production line moisture measurement problems formerly beyond the capability of a single instrument. A nomagraph accompanying each model eliminates calibration curves on papers and similar materials of known density, enabling complete percentage moisture content readings on the spot in a few seconds. The instrument gives accurate measurements in the 0 to 40 percent moisture range within close tolerances. Through the use of a new roller-type electrode, the Model PM is capable of detecting wet streaks or uneven distributions of moisture while paper rolls are in motion. The instrument's excellent mobility allows instant answers on any part of the moving paper rolls or other similar materials for immediate corrective action where necessary. The Plug-in, roller type electrode consists of two hardened metal rollers, ball bearing mounted for long life and smooth operation on moving material. It will accurately test stationary rolls, stacks and skids, showing moisture distribution patterns measuring by radio frequency determination of the dielectric constant of the sample. Additional plug-in electrodes are available for thin penetration and deep penetration testing. A separate probe has been designed for specific use on hardboard. The Model PM is completely portable, weighing five pounds and is easy to use. Voltage fluctuations of 90-130 volts are automatically compensated. Zener diodes protect the meter against overloads. The Model PM complete sells for $325 and additional electrodes are $65 each.

Send for Information
Additional information regarding new products or new literature items appearing in the "What's New?" department can be obtained by writing in the key number of the item in the Product Education Service coupon which appears on page 86.

★ ★ ★

P-4-1—The Optron Displacement Follower for daylight operation has recently been announced. This is a device for measuring vibration, motion and displacement of mechanical parts without physical contact with the work being measured. The optical-electronic instrument focuses a small spot of light on the edge of the work. A fast electronic servo causes this spot to follow the motion of the work. The instrument may be used to measure amplitude, frequency and waveform of shaketables, accelerometers, velocity pick-ups, mounted assemblies and components on shaketables, relay contacts, governors, valves, control linkages and vibration machinery. Any motion in any plane can be measured. The "Daylight" 701 is similar to Models 401, 301, 250, 1 and 010, but it may be set up, operated and calibrated in an ambient illumination to 40 footcandles of either daylight or incandescent light (usual illumination in a machine shop or on an office desk.) Three interchangeable lenses are available to cover displacement ranges of 0.050, 0.100, 0.500 inches peak to peak amplitude full scale. Other models are available for ranges up to ten inches.

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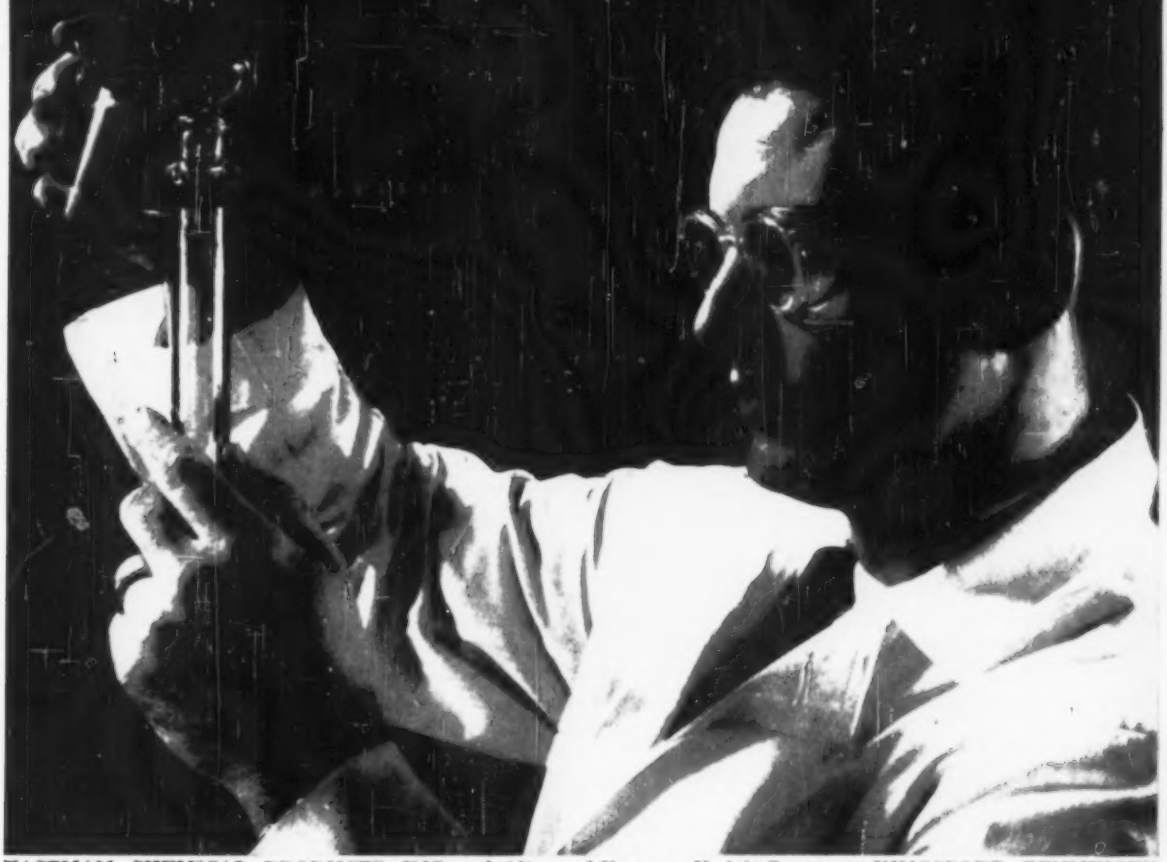

EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE

Who would rock a chair 750,000 times?

Why was this sash lift so difficult to make?

Question

Answer

The Homecrest Company of Wadena, Minnesota, did! This furniture company wanted to add a modern rocking chair to its line of functional home furniture—but only if the chair could be a quality item that would give good, dependable service. The AS&W Spring Engineering Research Service studied the problem and recommended a pair of round wire helical single coil torsion springs. Using these springs Homecrest designed the chair. The chair was then put through a test that far exceeded any amount of service it would get in normal home use. Under a 250-pound weight, the chair was mechanically rocked 750,000 times without showing any sign of failure. The Homecrest Company has now manufactured 20,000 of these chairs—and not one has failed.

This sash lift locks simple enough, but it caused the manufacturer, Amerock Corporation of Rockford, Illinois, plenty of trouble. The strip steel originally used failed under the severe double drawing operation. But then Amerock brought the problem to American Steel & Wire. The AS&W metallurgists recommended a #2 Finish USS Amerstrip which fulfilled the deep drawing requirements, and held a finish suitable for plating. Joe Ellis of Amerock said, "AS&W did an excellent job in developing a strip steel which would do this difficult double draw, yet maintain its finish for plating. We have had more trouble from other steels doing simpler jobs." Another example of the ways AS&W tailors the products of its Manufacturers Division to meet the customers' requirements.

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SECTION CALENDAR (MAY 25—JUNE 31)

SECTION	DATE	PLACE	TIME	SUBJECT	SPEAKER
Cincinnati	June 13	———	———	Annual Dinner Dance	———
Columbus	June 13	Desert Inn	6:30	Business Meeting	———
Harrisburg	June 3	The Stone Barn, Millersville	6:30 pm	Chicken Barbecue and Installation of Officers	———
Los Angeles	June 11	Rodger Young Auditorium	6:00 8:00	Clinic Computer Application In the Chemical Industry	Seymour Porter, U.S.C.
Mid-Hudson	June 2	Germania Hall, Poughkeepsie	7:00	Annual Social Evening	———
Montreal	June 3	La Salle Canadiene, Windsor Station	6:30	Annual Business Meeting & Dinner	———
Portland	June 2	Lucky Lager	7:30	Installation of Officers	———
San Antonio	June 18	Lone Star Brewery Co. (Picnic Area)	6:30	Annual Picnic & Installation of Officers	———
State Univ. of Iowa	June 4-5	———	———	MIL-STD-414: Theory and Applications	Dr. L. A. Knowler, State Univ. of Iowa
Tucson	June 11	———	———	Social Meeting & Dinner Dance	———
Tulsa	June 15	Borden's Cafeteria, Sheridan Village	6:15	Scrap Reduction Programs	B. M. Appleman, Texas Foundries, Inc.

P-4-2—Groups of seven different cams, arranged in stacks are checked for contour, proper stacking, and broken or chipped edges on a semi-automatic Federal electric gage. A master cam stack is permanently fixed on a precision locating shaft. The stack to be checked is positioned precisely on the same shaft and held tightly in place by a pressure plate. Reference contacts ride the contours of each of the seven cams in the master stack. The sensitive gaging contacts which check the workpiece are coupled to the reference contacts by means of pantographs and follow them exactly as the shaft is rotated. Electrified dial indicator gaging units, called Electricators, contact the pantographs and any difference between a reference contact and its sensitive counterpart causes the Electricator spindle to move. The spindles actuate switching contacts which control signal lights. By glancing at the bank of lights mounted above the gaging station, the inspector can quickly ascertain the acceptability of the entire stack of cams. To make comparative measurements, it is necessary to have a master, and in cam measurement the master must conform to the exact shape needed to produce the proper movement of the cam-follower. Comparing these irregular surfaces by ordinary methods is exceedingly complicated, but by linking a sensitive gaging contact with the reference contact which is guided around the contour of the master, it is fairly easy to make a comparison between the relative position of the two gaging contacts.

★ ★ ★

P-4-3—Mid-eastern Electronics, Inc. offers a line of certified Laboratory Standard Resistors for use with the company's Megatrometer in measuring resistance in the ultra high megohm range. Standard Resistors are available in four values: 10 megohms, 100 megohms, 1,000 megohms and 10,000 megohms. Each unit is certified to 0.2 percent and is supplied with a temperature curve. Prices range from $72.00 to $138.75 each. The Resistors are mounted in a Faraday Box which plugs directly into the Megatrometer. Teflon insulation, guard rings and special silicone treatment virtually eliminate surface leakage. The Laboratory Standard Resistors supplement the company's line of Reference Resistors offered in values from 1000 megohms to 10 million megohms certified within 1.0 percent.

★ ★ ★

P-4-4—Dynametrics Corp. has developed a Pneumatic Gauge Tester to be used as an accurate and dependable primary standard in gauging and calibration of all instruments measuring pressure. The instrument features an unusual range of pressures with provision for any pressure-reference between zero absolute and 500 psi gauge. Standard weight sets permit incremental measurement of 0.1 psi. Accuracy is 0.015 percent of a full scale. Power requirment is 105-124 volts, 60 cps, 3 watts. Pressure is supplied by a self-contained, filtered pressure source plus provision

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for external source. There is a built-in pressure bleed valve. The case is vented to atmosphere or may be evacuated for reference to a lessor pressure.

★ ★ ★

P-4-5—Rese Engineering has announced the Model 4012 Automatic Memory Core Handler for fully automatic or manual rate feeding of standard,, 0.080 inch O.D., miniature ferrite memory cores to a testing point, in pilot line or full scale production line testing. Operating at a maximum handling rate of 3600 cores per hour, the instrument provides for the separation of the tested cores in five different grades. The grades, as well as the rate of handling, are selected by the operator or by fully automatic core analysis equipment such as the Rese React. For laboratory analysis of moderate quantities of cores, provision has been made for holding the core in the test contacts for an indefinite length of time to observe its voltage response. The grading method allows the tested cores to be deposited in one of five grade bottles, making the 4012 particularly suitable for statistical analysis of core production and for memory applications where it is desired to group cores according to specifications of peaking time, switching time, value of "zero" response, and/or value of "one" respons-. The new core handler system is comprised of the electromechanical handler mechanism, a remote manual control unit, and the electronic control unit, which includes power supplies and transistor operated control logic and timing circuits, and which may be placed at any location remote from the actual handler mechanism. Maintenance is facilitated by modular plug-in card type construction, and higher production rates can be attained by operating two 4012 handlers in time multiplex. Cores are fed from a vibrating reservoir under the influence of a magnetic field which lines up the cores in tangential links and allows one core at a time to pass through an escape flue to position itself upon a metallic shoe. Here it is picked up by one of four revolving test pins which carries the core into two sets of contacts. Programmed pulses are applied to the core through one set of contacts, while the second set of contacts picks up the induced voltage output from the core. This response is examined by the operator or an automatic decision making circuit, which energizes one of the five pick-off stations where the core is magnetically removed from the pin and dropped into the proper grade reservoir.

★ ★ ★

P-4-6—The new Dice Digital Read Out Micrometer capable of making twenty or more readings per minute to accuracies of 20 millionths has just been announced. The instrument is specially designed for production use by unskilled operators and is particularly suitable for those industries working with fragile or compressable materials. Measuring pressures can be used from approximately zero pressure up to 20 grams, depending on softness or hardness of material involved. Measurement is shown on a counter with large, easily read numerals. When used within the designed measuring range, the instrument is its own reference standard and the need for gage blocks is eliminated.

★ ★ ★

P-4-7—Weighings now can be made in one-third of the time formerly required with the new Torsion Dial Balance. The new design features a simple graduated dial which can be turned without arresting the oil-damped balance, replacing the time consuming "cut-and-try" procedure. The portion of the weighing below one gram is "dialed in" to an accuracy of ten milligrams. The dial mechanism retains its original accuracy after more than a million weighings, and is unconditionally guaranteed by the manufacturer. Previously most laboratory balances used a graduated beam and slide weight for "fine" weighing after the weight had been determined within one gram. The new Dial Balance is available in two models. DLT2 has a capacity of 120 grams and a sensibility reciprocal of ten milligrams. DLT2-1 has the same specifications but is equipped with a polished stainless steel scoop for bulk material. The metal case has a corrosion resistant gray finish constructed to exclude dust and chemicals. The hinged lid is $2^3/_4$ inches high

Institute of Statistics, North Carolina State College

A one-week intensive short course in "Statistics methods for research workers in industry and the physical sciences will begin the week of Aug. 10. The course, sponsored by the Institute of Statistics at North Carolina State College, will be held at Brevard College in Brevard, N. C. An elementary and an advanced section of the course will be offered.

Lectures in the elementary section will cover basic concepts, confidence limits, tests of significance, correlation and curve fitting, analysis of variance, and an introduction to design of experiments.

Among the topics to be included in the advanced section will be variance components, multiple regression, response methods, and experimental design.

A registration fee of $125 will be charged. Enrollment will be limited to 50 students in each section.

For further information write Division of College Extension, Box 5125, State College Station, Raleigh, N. C.

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with a glass front and top. The unit measures 11½ × 6 × 8¼ inches.

★ ★ ★

P-4-8—General Electric has announced a new X-ray Gage for measurement of low density materials such as paper, fabrics, sheet and film-like materials. The newly developed gage, with a source that can be turned "on" and "off", employs very soft x-rays which should make it more desirable for gaging operations in many industries which have been employing other devices. X-ray gages do not require the constant precautions of nuclear gages which employ radioactive isotopes. When the gage is "off" the source is "off". The gage also eliminates the necessity of obtaining AEC licenses and the maintenance of special laboratories for handling the radioactive isotope source materials of non-x-ray-type gages. The new G-E gage with its very soft x-ray is well suited for many industries and the company is prepared to discuss specific applications with manufacturers who have low density material gaging problems.

★ ★ ★

P-4-9—In quality control systems and statistical analysis, the multiple-unit hand-operated counter, made by Veeder-Root Inc., is an effective expediter as well as a safeguard for accuracy. Typical uses in inspection include classification of rejects by number and type; checking of incoming lots, in-process and final inspections; attribute sampling to compare several lots on successive tests; frequency distributions to give immediate readings in variable sampling, lot-plot, etc. Vary-Tally Counters are now available in single units or in stock combinations up to 72 (6 banks with 12 units across in each row) and one whole row can be reset to zeros with one turn of a single knob.

★ ★ ★

P-4-10—A complete change in the line of Webber Rectangular Steel Gage Blocks to incorporate new higher accuracies and greatly reduced prices has been made. Rectangular steel blocks formerly classified as Grade A with accuracies of +0.000004 inch and −0.000002 inch are now called A+ by the manufacturer, and the price of an 84-block set (including two 0.100 inch wear blocks of Croblox) has been reduced from $413.00 to $287.50. These new A+ blocks are of inspection quality, priced for everyday shop use. In addition, an entirely new classification of Webber Rectangular Steel Gage Blocks has been created, featuring ±0.000002 inch accuracies. Known as Grade AA, the new blocks are priced at $555.00 for an 84-block set. The former Grade B line has been discontinued. The Grade A+ and AA classifications have been made because accuracies of the blocks exceed those specified by the U. S. Bureau of Standards for Grade A blocks. This upgrading of the complete line has been made possible by new, high efficiency equipment designed and built by Webber. Rectangular Steel Blocks are now packaged in tough, new plastic chests which are resistant to weather, non-absorbent, easy to clean, and designed to withstand hard usage. They feature a frosted walnut grain Melamine exterior and black Bakelite interior. White plastic identification strips permit easy visability of gage block sizes.

New Literature Available

L-4-1—The Thwing-Albert Instrument Co. is once again writing and publishing its news bulletin "Facts on Testing". The bulletin is written and published to inform technical people concerned with the physical testing of new developments in test instruments, new testing methods, new applications for test instruments, short cuts discovered by other readers, new useful accessories for instruments, and trends in testing research and development work. Instruments and techniques described are of primary interest to the paper industry.

• • •

L-4-2—CEA Bulletin BR 111.1 describes in detail a new Range and Balance Unit. The new unit balances out small inequalities in bridge arm resistance. Its features include gold contact relays that minimize "Dry circuit" problems; a front panel switch for changing to auxiliary power supplies; pushbuttons for controlling both Range and Balance, and a remote switch for setting all channels into two standardization modes.

• • •

L-4-3—An 8-page brochure entitled, "Manometers—Theory and Application"

(Continued on page 86)

clinics, conferences, and courses

MAY

. . . ***25-27—13th Annual Convention and National All-Industry Quality Control & Production Exposition, Public Auditorium, Cleveland, Ohio, sponsored by ASQC.***

. . . ***31-June 5***—Tenth Annual Industrial Research Conference, Research Operation and the Research Manager's Job, Arden House, Harriman, N. Y., sponsored by Department of Industrial and Management Engineering of Columbia University, contact M. F. Garvey, Columbia University, 409 Engineering Bldg., Harriman, N. Y.

JUNE

. . . ***8-July 17***—Southern Regional Graduate Summer Session in Statistics, North Carolina State College, Raleigh, N. C., contact F. E. McVay, Dept. of Experimental Statistics, North Carolina State College, Raleigh, N. C.

. . . ***9-19***—Design of Experiments Short Course, Purdue University, Lafayette, Ind., contact Prof. Charles R. Hicks, Purdue University, Lafayette, Ind.

. . . ***9-19***—Advanced QC Short Course, Purdue University, Lafayette, Ind., contact Prof. Irving W. Burr, Purdue University, Lafayette, Ind.

. . . ***15-25—Statistical Methods for Process Development, University of Chicago, Chicago, Ill., sponsored by Chemical Division of ASQC, contact Dr. H. P. Andrews, Research Laboratories, Swift & Co., U. S. Yards, Chicago, Ill.***

. . . ***15-27***—20th Annual Management Course, State University of Iowa, Iowa City, Iowa, contact J. Wayne Deegan, 122 Engineering Building, State University of Iowa, Iowa City, Iowa.

. . . ***16-19***—Annual Industrial Engineering Seminars, Cornell University, Ithaca, N. Y., contact Andrew Schultz, Jr., Dept. of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, N. Y.

. . . ***20***—Six-day intensive course in QC for the Graphic Industries, Rochester Institute of Technology, Rochester, N. Y., contact Harold Kentner, Asst. Director Extended Services, Rochester Institute of Technology, 65 Plymouth Ave. So., Rochester, N. Y.

. . . ***22-26***—Symposium on Education in Materials, (ASTM Annual Meeting), Atlantic City, N. J., sponsored by ASTM and ASEE, contact ASTM, 1916 Race St., Philadelphia 3, Pa.

. . . ***29-July 10***—Foundations and Tools for Operations Research and the Management Sciences, University of Michigan, Ann Arbor, Mich., contact R. E. Carroll, Coordinator of Engineering, Summer Conferences, University of Michigan, Ann Arbor, Mich.

JULY

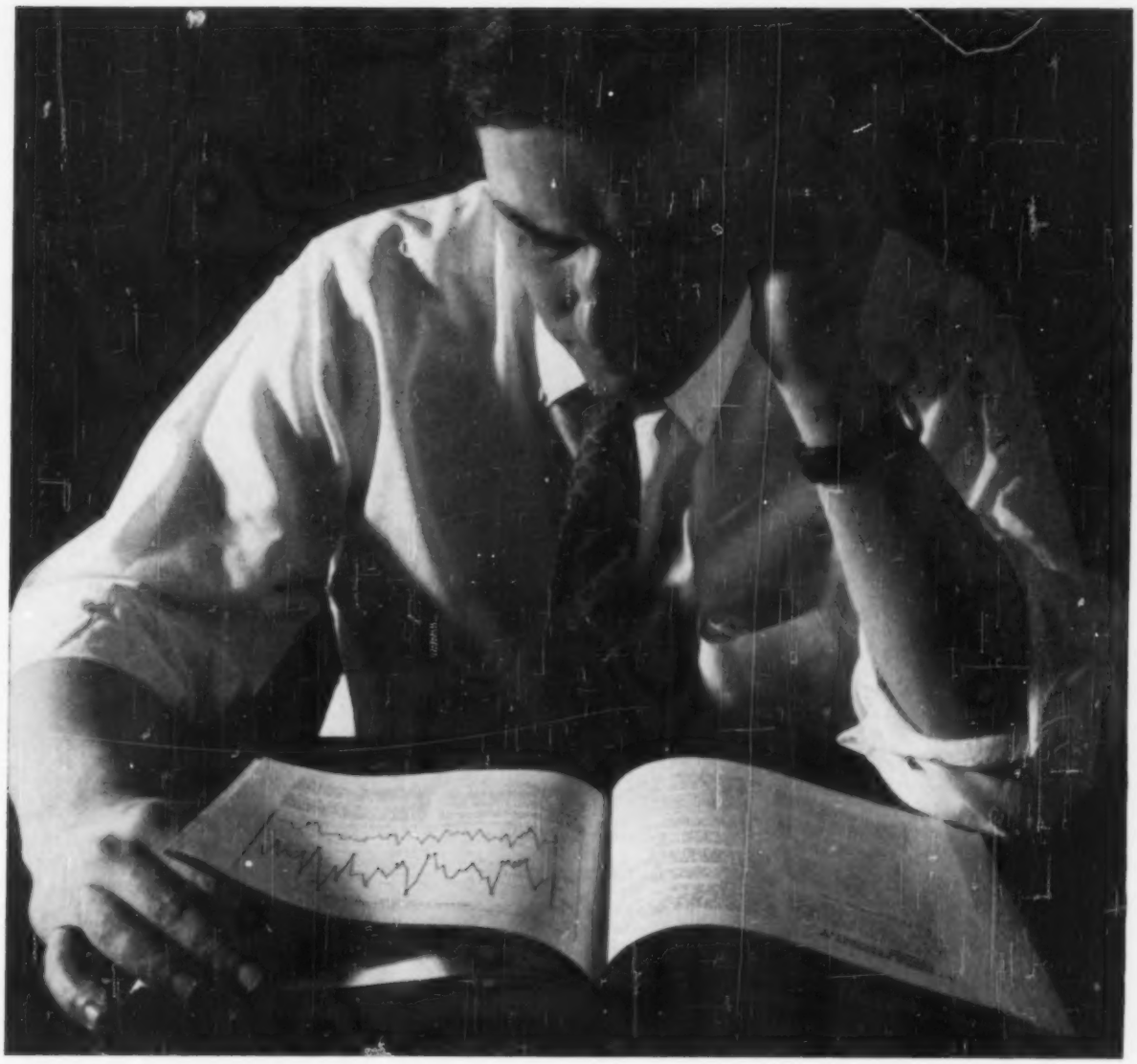
. . . ***20-31***—8th Pulp and Paper Statistics Course, Dartmouth College, Hanover, N. H., cosponsored by TAPPI and Technical Section of CPPA, contact A. J. Winchester, Technical Association of the Pulp & Paper Industry, 155 E. 44th St., New York 17, N. Y.

AUGUST

. . . ***10***—One-week intensive short course in Statistics Methods for Research Workers in Industry and the Physical Sciences, Brevard College, Brevard, N. C., sponsored by the Institute of Statistics at North Carolina State College, contact Division of College Extension, Box 5125, State College Station, Raleigh, N. C.

. . . ***17-27***—12th Annual Intensive Course in QC by Statistical Methods, University of Michigan, Ann Arbor, Mich., contact Prof. C. C. Craig, 106 Rackham Building, Ann Arbor, Mich.

. . . ***17-28***—Courses in Frontier Research on Digital Computers, University of North Carolina Extension Division, Chapel Hill, N. C., contact James G. Steagall, University Extension Division, Box 1050, Chapel Hill, N. C.



New Western Electric contribution to SQC

Recently a new book, the *Statistical Quality Control Handbook*, began appearing in Western Electric plants around the country. It was prepared and published by W. E. to help train employees in the principles and techniques of SQC.

This handbook of well over 300 pages contains an extensive description of the methods used at Western Electric in applying SQC to manufacturing operations. In making these methods known throughout the company, we hope to inspire further study and broader application of SQC.

This new book is additional proof of Western Electric's belief in quality control. We first began applying SQC to our operations over 25 years ago. Now it is being used in all our plants. The benefits to our job—as manufacturing and supply unit of the Bell System—have been substantial . . . helping us produce consistently dependable telephone equipment at low cost.

Others may find this handbook useful as a guide for applying SQC to their operations. A limited number of copies are available and can be obtained for $7.50. Inquiries should be addressed to: Superintendent Quality Assurance, Western Electric Company, 195 Broadway, New York 7, N. Y.

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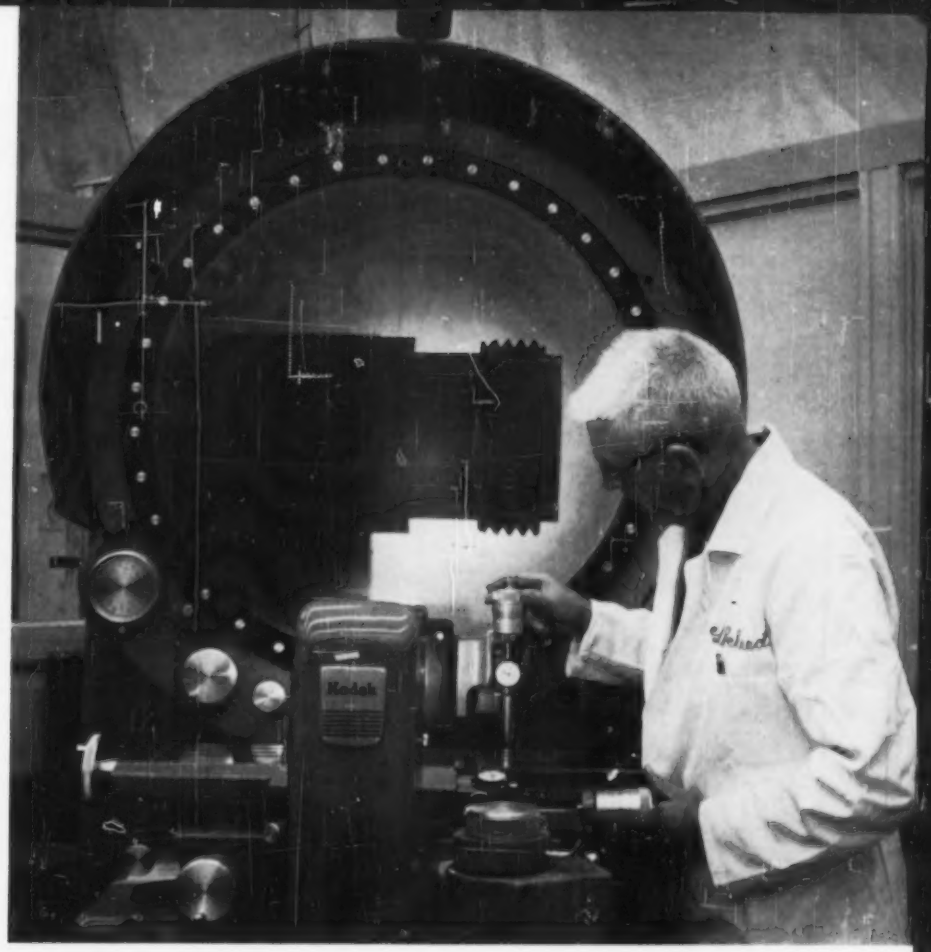

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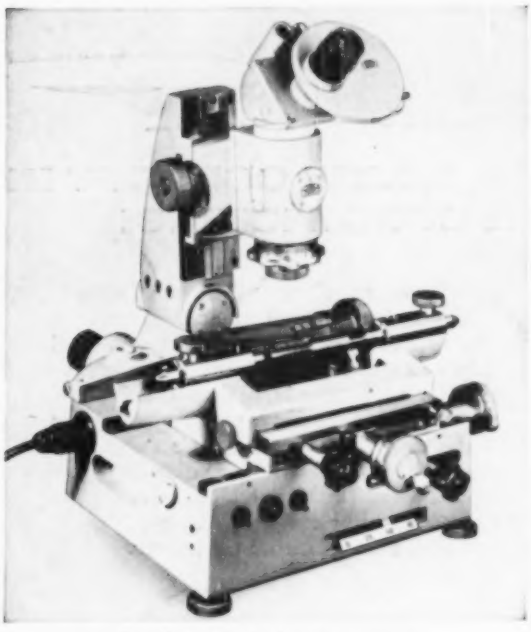

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